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Robert Selbie Clark.

1882—1950.

Robert Clark was an Aberdonian and the greater part of his life centered round his native city Aberdeen. Educated at its Grammar School, he spent two periods of study at its ancient University, from 1901 to 1905 and from 1908 to 1911, taking his Arts degree in 1908 and his Science degree in 1911, the interval being spent in teaching at Blairgowrie and Aberdeen. In his zoological studies he came under the influence of an inspiring teacher, the late Sir J. A. Thomson, and on leaving the University he was appointed zoological assistant to Dr. W. S. Bruce, Director of the Scottish

National Antarctic Expedition, and worked in Edinburgh on the "Scotia" collections, helping to edit the "Scotia" Reports, to which he contributed papers on freshwater and sea fish. He was allotted a Carnegie Research Scholarship in 1912, but resigned this in December of the same year on his appointment as Naturalist on the staff of the Marine Biological Association at Plymouth. Here he continued his work on fishes, devoting his attention chiefly to the mackerel, herring, and pilchard. At the beginning of August 1914, he volunteered at short notice to join the Shackleton Expedition to the Antarctic as marine biologist. The epic story of the crushing of the "Endurance" in the ice of the Weddell Sea, the journey across the ice to Elephant Island, the boat journey by Shackleton, and the eventual rescue will always be remembered. Clark was one of the party that huddled under an upturned boat on Elephant Island. He would rarely talk of this terrible experience, but often recalled with pleasure the hospitality received in Chile and Argentina on the way home. In later years he looked forward every year to meeting his Antarctic colleagues at an annual dinner. On his return from the Antarctic in 1916 he joined the Navy and saw service in minesweepers. Resuming his post at Plymouth in 1919, he settled down to continue his study of the larval and post-larval stages of teleostean fishes, laying, as Mr. F. S. Russell tells me, the foundation of local knowledge on this subject. He also became an expert on the skates and rays, and on their eggs and embryos. His papers on these subjects are to be found in the *Journal of the M. B. A.* (1914, 1920, 1922, and 1927) and in the *Scientific Investigations* of the Fishery Board for Scotland (1926).

In the autumn of 1923 he left Plymouth for Aberdeen, to take up the post of Senior Naturalist under the Fishery Board, and henceforward his energies were directed to the problems of fishery research. He took his D. Sc. in 1925. On Dr. Bowman's retirement through severe illness, Dr. Clark succeeded him in 1934 as Scientific Superintendent, and continued to direct fishery research in Scotland till his own retirement in 1948.

Clark's association with the International Council started in 1924, and he was a regular attendant at the meetings from 1933 onwards. He succeeded Bowman as Chairman of the Northern North Sea Committee in 1935, and the present writer as Chairman of the Consultative in 1946. He acted as Convener of several Special Meetings, notably the meeting of Herring Experts at Aberdeen in 1946, and the Herring Meeting

at Edinburgh in 1949, and contributed valuable papers on herring larvae, haddock investigations, and other subjects to the Council's publications. He was particularly interested in the herring, and had accumulated a great amount of data on the distribution of the larval stages, much of it unfortunately still unpublished.

During the war he served on a number of important Committees, particularly the small Interdepartmental Committee on Overfishing, whose report, accepted by the British Government, formed the basis of later international negotiations on this question, at the International Overfishing Conference of 1946 and subsequent meetings of the Standing Advisory Committee. He was a member also of the Committee on Post-war Fishery Research set up by the Development Commission to advise on the scope and organization of fishery and marine biological research in Great Britain. For many years he was a Trustee of the Buckland Foundation, which promoted lectures and publications on fishery subjects.

Robert Clark was a man of powerful physique, and in his younger days he was a brilliant cricketer, of more than local renown. He captained the Aberdeenshire side for some years and on several occasions played for Scotland. When at Plymouth he played for Devon County. He was also a first-rate golfer, and was never so happy as when he could get off for a few days salmon fishing.

He was not an easy man to know; his Scottish reserve and occasional brusqueness of manner were apt to deceive the stranger. But these hid a personality of much charm and kindliness, often diffident of its own powers and very modest. His many friends — of whom I was proud to be one — regarded him with great affection, and mourn his loss.

E. S. Russell.

The Recent Increase in Salinity off the Coasts of Finland and its Influence upon the Fauna.

By

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AS is well known, the salinity of the Baltic has been rising during the last three decades, owing to a strengthened inflow of salt water from the North Sea through the Sound and the Belts. The reason for this phenomenon is still under discussion. In the main it seems to have been caused by unusual wind conditions. Whatever the reason may be, the fact as such is of considerable interest to the zoologist. Thus, for instance, the remarkable abundance of the cod (*Gadus morrhua*) in the Baltic in recent years is ascribed to the increase in the salt concentration of the water (see, for example, Kändler, 1949). Not least, the zoologist working in the inner, highly diluted parts of the Baltic basin, in which marine forms are poorly represented, has had reason to follow the rise of the salinity curve with interest and attention. As we shall soon see, there are also clear signs of an amelioration of the living conditions for marine animals even so far from the mouth of the Baltic as the coasts of Finland.

As was shown in a recent paper by Granqvist (1949), the increase of salinity in Finnish waters was first observable in the early 30's and, more clearly, in 1938[1]). These early records relate to the south coast. On the west coast of Finland unusually high salinity values were not observed until 1943. This dissimilarity is caused by the well known difference in the nature of the junctions of the Gulf of Finland and of the Gulf of Bothnia with the central Baltic; whereas the Gulf of Finland is a direct continuation of the central basin, the Gulf of Bothnia is separated from it by a sill. In the following paper, only the southern

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[1]) The recent salinity rise on the coast of Finland has also been discussed by Lisitzin (1948). The first biologist to draw attention to the phenomenon was Erkamo (1942; but see also Välikangas, 1942).

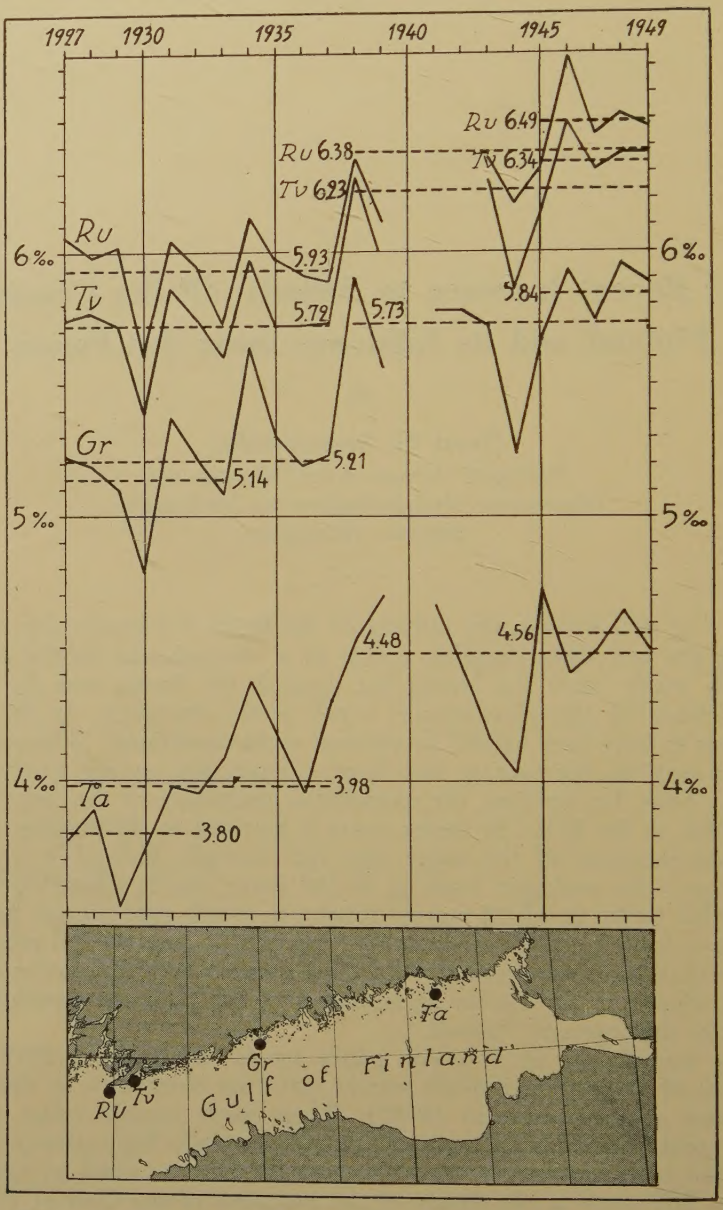

Figure 1. Showing the increase in salinity on the south coast of Finland (see also Table I, p. 105). The continuous lines refer to annual means, and the broken lines to period means. The location of the stations is shown in the accompanying chart (*Ru* Russarö, *Tv* Tvärminne, *Gr* Gråhara, *Ta* Tammio).

Finnish coast (and the adjacent eastern waters now belonging to Russia) will be considered.

The table below and Figure 1 give an idea of the salinity during the period 1927—49 at four of the hydrographical stations of the Institute of Marine Research of Finland, viz., Russarö, Tvärminne, Gråhara (Harmaja), and Tammio (Stamö). The year 1927 was chosen as the start of the period, because it marked the opening of the hydrographical

Table I. Salinity ‰ at 5 m. at Russarö, Tvärminne, Gråhara (Harmaja), and Tammio (Stamö), 1927—49.

Annual Means.

Year	Russarö	Tvärminne	Gråhara	Tammio
1927	6·05	5·74	5·22	3·77
1928	5·98	5·76	5·19	3·89
1929	6·02	5·72	5·10	3·52
1930	5·61	5·39	4·79	3·72
1931	6·04	5·86	5·38	3·97
1932	5·94	5·75	5·22	3·95
1933	5·73	5·60	5·08	4·09
1934	6·13	5·97	5·64	4·38
1935	5·97	5·72	5·30	4·16
1936	5·91	5·72	5·19	3·95
1937	5·84	5·73	5·23	4·30
1938	6·35	6·29	5·90	4·54
1939	6·11	5·95	5·56	4·70
1940	—	—	—	—
1941	—	—	5·78	4·67
1942	—	—	5·78	4·42
1943	6·36	6·27	5·72	4·16
1944	6·18	5·85	5·23	4·03
1945	6·31	6·14	5·67	4·73
1946	6·73	6·49	5·93	4·41
1947	6·44	6·31	5·74	4·50
1948	6·51	6·37	5·96	4·65
1949	6·47	6·37	5·88	4·50

Period Means.

	Russarö	Tvärminne		Gråhara	Tammio
1927—37	5·93	5·72	1927—33	5·14	3·80[1])
1938—49	6·38	6·23	1927—37	5·21	3·98
1945—49	6·49	6·34	1938—49	5·73	4·48
			1945—49	5·84	4·56

[1]) 1927—32.

Note:— The figures tabulated are based on data published by the Institute of Marine Research of Finland for the years 1927—46, and on unpublished data for 1947—49. The normal rate of sampling is 3 times a month. The breaks in the series are due to the war. To minimize the occasional effect of river overflow, values of salinity differing by more than 25 % from the annual mean have been disregarded.

station at Tvärminne, which is of special interest to the biologist (see below). Of the depths investigated by the Institute, 5 m. was chosen, as the present study concerns the fauna living in shallow water and as the data referring to this depth give a truer picture of the salinity available to the animals in question than do surface values. For in winter these values may be greatly lowered by a quite shallow layer of fresh water derived from rivers; in many cases this layer has a depth of only a few decimetres or even centimetres.

The table and diagram show that the increase in salt concentration was first observable in the east, i.e., at Tammio and Gråhara, where the years 1933 and 1934 both clearly exhibit salinities higher than those of preceding years. This regional difference is no doubt due to the shallowness of the water in the east, which allows the salt deep-current flowing in from the central Baltic to influence the upper layers more rapidly there than in deeper regions. At the western stations, Tvärminne and Russarö, this first increase in salinity is less pronounced, but all stations show a second, marked rise of the curve in 1938. Since then in most years the salinity has remained high, the mean for the last five years being especially high.

It will be seen that the rise in salinity is particularly noticeable, if we compare the means for the late '20's and early '30's at the eastern stations, Gråhara and Tammio, with that for the last five years. The differences amount to 0·70 and 0·76 ‰ respectively. A comparison of the longer periods 1927—37 and 1938—49 gives a rise in salinity varying from 0·45 to 0·52 ‰ at the four stations.

This increase in salinity on the Finnish coast, averaging from about one half to three-quarters ‰, is, admittedly, not very great. But in view of the sensitiveness of aquatic invertebrates to changes in the salt concentration of the water, it is nevertheless of no little interest to the biologist. As has already been mentioned there are in fact signs that the salinity rise has rendered the living conditions for marine animals more favourable than before in the waters under consideration. The present report will be confined to the clearest of these indications, which is that given by the jellyfish, *Aurelia aurita*.[1])

This species, which is the only jellyfish belonging to the Finnish fauna, has long been known on the south-west coast; the full-grown stage may occur there in masses in late summer and autumn. Formerly it was assumed that these swarms of *Aurelia* had been transported from the open, salter Baltic. Investigations carried out in the south-west archipelago in 1921—35 by Wikström (Wikström, 1921, 1924, 1925, 1932, 1936) clearly indicated, however, that *Aurelia* is capable of reproduction in these waters, as ephyrae and subsequent small free-living stages and even scyphistomata were found (Fig. 2).

[1]) Representatives of this animal group are, in fact, very useful indicators of changes in salinity. First, they are easily observable, thanks to their considerable size. Second, practically every year larvae are transported with drifting adult females far beyond the area in which they grew up. If salinity rises, new regions may thus be occupied much more rapidly than in the case of benthonic animals.

There are unmistakable signs that the reproductive area of *Aurelia* has extended in Finnish waters since the beginning of the recent salter period. At the Zoological Station at Tvärminne, situated at the mouth of the Gulf of Finland (see Figure 2:T), that is, east of the area studied by Wikström, no ephyrae or other small stages of *Aurelia* were caught in the period from 1901 (the foundation of the Station) until 1939. In that year representatives of both categories were observed, and have been observed since then, in every summer that biologists have worked at the Station, i.e., since 1946 (from 1940 to 1945 war conditions prevented work there). It may be noted that plankton catches have been made at Tvärminne every summer since 1920, mainly in connexion with the hydrobiological courses given there. Later on quite small specimens of *Aurelia*, indicating local reproduction (maximal size 1 cm.), were reported by zoologists still farther eastwards, the easternmost find being from Porkala, about 50 km. east of Helsingfors (Helsinki). [1])

The observation of the first ephyrae at Tvärminne coincides with the beginning of the salter period in these waters. It has been mentioned that the first year of remarkably high salinity there was 1938. Consequently, there must have been exceptionally good conditions for the larvae and their development into scyphistomata in that year, and accordingly for the appearance of ephyrae in the following year.

The observations in recent years of drifting adult *Aurelia* also point in the same direction. Up to 1939 full-grown animals were reported no further to the east than a little eastward of Helsingfors, but later on specimens were found about 120 km. further east (see Figure 2).[2])

In order to obtain some idea of the saltness required by *Aurelia* for reproduction, the author has subjected the salinity conditions in the waters where signs of reproduction were observed to a closer scrutiny. This is possible, thanks to the abundant data from neighbouring hydrographical stations (see Figure 2) which are published by the Institute of Marine Research.

This analysis of the relationship between salinity and the reproduction of *Aurelia* has led to the following conclusions:—

1) The decisive period is September-December. During this time the salinity must not fall below a value rather more than 6 ‰ — perhaps 6·1. According to Bogucki (1933), who has studied the life-cycle of the species under discussion on the coast of Poland, free-

[1]) Purasjoki, who reports the occurrence of small *Aureliae* near Porkala (Purasjoki, 1947), regards this as evidence of an eastward extension of the range of the species. The same conclusion was drawn by Välikangas (1942) from his observations of drifting adult *Aureliae* in the waters east of Helsingfors.

[2]) These easterly records were kindly placed at the author's disposal by Dr. Ilmo Hela, of the Institute of Marine Research, who has recently circulated a questionnaire about the occurrence of full-grown *Aurelia* on the Finnish coasts. As will be seen in the paper Dr. Hela is to publish on this subject, he has come to much the same conclusions as those reached in the present paper, on the basis of observations of earlier developmental stages, as to the extension in recent years of the reproductive range of *Aurelia*.

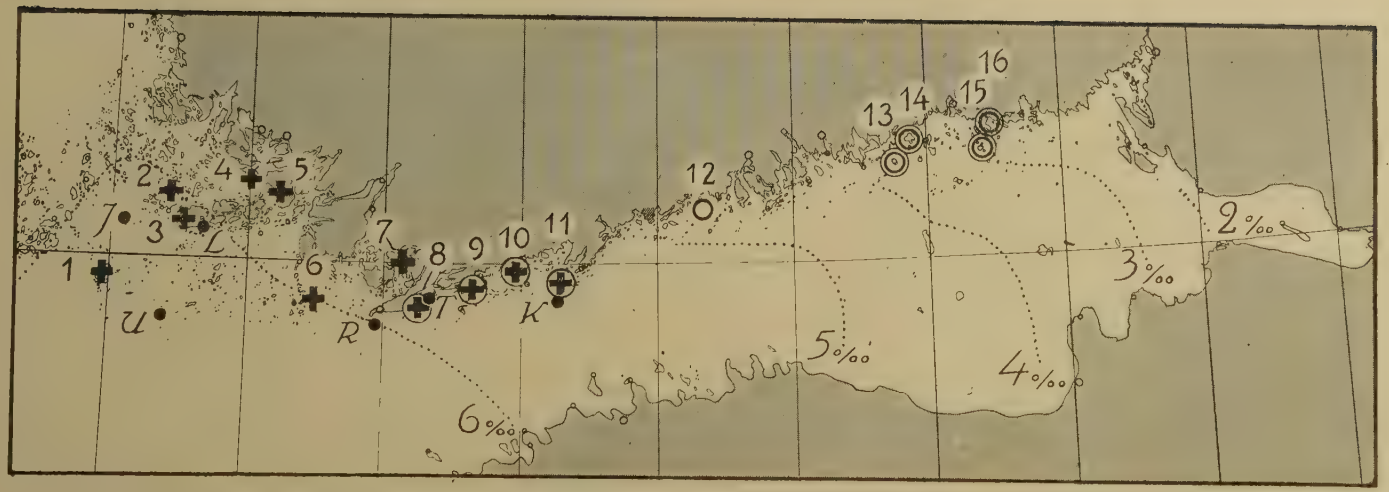

Figure 2. Showing the extension of the area of occurrence and reproduction of the jellyfish, *Aurelia aurita*, on the south coast of Finland.

+ Signs of reproduction observed before 1939.
⊕ Signs of reproduction observed after 1939.
○ Easternmost finds of adult medusae before 1940.
◎ Easternmost finds of adult medusae since 1940.

Hydrographical stations: *U* Utö, *J* Jungfruskär, *L* Lohm, *R* Russarö, *T* Tvärminne, *K* Kallbådan (Porkala). The isohalines, taken from the "Atlas of Finland" (1925), give a fairly good idea of the salinity in the period 1927—37, preceding the salinity rise.

Observations of *Aurelia:* 1. Kökar, before 1931: small medusae (Wikström, 1932). — 2. Houtskär, 1919—22: small medusae, 1931: scyphistomata (Wikström, 1921, 1924, 1925, 1932). — 3. Korpo, 1923—25: small medusae (Wikström, 1932. — 4. Rymättylä, 1933, 1935: small medusae, 1934: scyphistomata (Wikström, 1936). — 5. Pargas, before 1931: small medusae (Wikström, 1932). — 6. Hitis, 1922: small medusae (Wikström, 1925). — 7. Bromarv, before 1931: small medusae (Wikström, 1932). — 8. Tvärminne, 1939: ephyrae (observed by the author), 1946—50: ephyrae and small medusae every summer (Siltamaa, 1947, Purasjoki, 1947, observations in 1948—50 by the latter and the author). In 1940—45 no observations were made at the Station on account of the war. — 9. Snappertuna, 1940, 1943: small medusae (observations by Prof. H. Federley). — 10. Ingå, 1940: small medusae (Segerstråle, 1940). — 11. Porkala, 1943: small medusae (Purasjoki, 1947). — 12. Sibbo, before 1940 (Välikangas, 1942). — 13. Pyttis, Fagerö (Kaunissaari), every year since 1940 (Hela, manuscript, see p. 107). — 14. Mussalo, 1940 (Ulvinen, 1940). — 15. Tammio, 1949 (Hela, manuscript, see p. 107). — 16. Klamila, 1949, (Hela, manuscript, see p. 107).

swimming larvae occur in September, October, and November, and attach themselves to the bottom and develop into scyphistomata in December. At the zoological Station at Tvärminne larvae, in aquaria, have been observed to attach themselves and develop as early as late August and September (communications by Prof. A. Luther and Mr. K. Purasjoki). At any rate the first developmental phase of the species undoubtedly falls mainly in the autumnal months. Thus *Aurelia aurita* seems to afford another example of the well known rule that the early stages of animals are more sensitive to unfavourable environmental factors than the later ones.

2) In the south-western archipelago the occurrence of scyphistomata and other young stages is attributable to reproduction in these waters in some only of those years in which they were observed by Wikström; in other years the salinity was too low early in the autumn of the same or — in the case of the ephyrae recorded — of the foregoing year. According to the hydrographical data the salinity, however, rose later on in the autumn (thanks to the autumnal convection) and reached a sufficiently high value to enable larvae which were at this time transported by currents from the southern, salter parts of the archipelago, to develop into scyphistomata and give rise to a new generation. In some years there was no reproduction at all in the area concerned, as the salt concentration of the water was too low throughout the whole year. The appearance of quite small *Aureliae* east of Tvärminne in recent years (Fig. 2) was also due to immigration of larvae from salter layers off the coast which were carried up by convectional processes in the late autumn of the preceding year and transported into the archipelago.

This upward trend of salinity on the coast of Finland is no unique phenomenon in these waters, even if only recent times are considered. It is well known that during the late and post-glacial periods the Baltic underwent a series of striking changes in salinity. During the short time for which more complete hydrographical data on conditions on the south coast of Finland are available, i.e., since 1905, the salinity was comparatively high from that year to the early '20's (cf. Granqvist, 1949). After this period the curve fell and remained comparatively low until the beginning of the salter period now discussed, i.e., until the middle and second half of the '30's. During this new rise, however, the salinity at some stations (cf. Granqvist, loc. cit.) has reached higher values than in the years from 1905 to the early '20's. It is to be hoped that the biologists working in the Baltic will pay due attention to the gigantic experiment which is once again being conducted there by Nature.

As has already been mentioned, the reason for the increased salinity in the Baltic in recent years is still under discussion. According to some hydrographers (cf. Kändler, 1949), the winds in the last few decades have been more predominantly westerly than before and have thus driven more salt water than normal into the Kattegat and thence into the Baltic. The preponderance of west winds, again, is said to be

connected with the change in climate in Northern Europe which has taken place in the last few decades.

As is well known, this climatic change is characterized by unusually mild winters. In consequence, the southern elements of the land fauna, e.g., mammals and birds have expanded northwards in Northern Europe. If this theory of the causes of the salinity increase in the Baltic proves correct, the change in climate would thus have favoured, in quite different ways, two very different ecological groups — on the one hand, the marine animals of the Baltic and, on the other, the southern components of the land fauna in neighbouring districts — a rather unexpected combination of results.

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The data on which the salinity means given in this paper are based were taken from the publications of the Institute of Marine Research of Finland, except those referring to the years 1947—49, which have not been printed so far and were kindly placed at the author's disposal in manuscript form.

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On the Application to Marine Research of the Meteorological Concept of Accumulated Temperature.

By

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THE view has previously been expressed by the writer (1945) that the relationship of physical oceanography, or hydrography, to marine biology is analogous to that of meteorology to agriculture. In the latter relationship, the direction in which correlation seems most effectively to have been demonstrated is that of air temperature (in a particular form) in relation to the yields of cereal and other crops (Hooker, 1907, 1921, 1922; Geddes, 1922; Yates, 1935). It is perhaps, on first thought, a little surprising that similar investigations seem never to have been attempted in the sea, but of course the reason lies in the inadequacy hitherto of both physical and biological data for particular regions over sufficiently long periods of time. The North Sea must be one of those sea regions of the world which have been most assiduously surveyed both physically and biologically for a considerable number of years, but even here, so far, it is only for a small part of its open-sea waters that a sufficient material has been assembled to demonstrate the lines upon which such investigation might usefully proceed.

The purpose of the following investigation, then, is to demonstrate, and to commend to fishery research biologists, one kind of hydrographical datum to which it seems likely that at least some concurrent marine biological phenomena might profitably be related. A prerequisite for the determination of the datum with desirable accuracy for its acceptance as a reliable basis from which to investigate the question of hydrographical-biological correlation is the systematic and fairly intensive collection of hydrographical observations. In this respect, in the particular investigation described below, the material, although evidently the best available for a region of like extent to that dealt with and over a comparable period of time, is yet scarcely

adequate for at least some of the years considered, to fulfil this condition satisfactorily. Nevertheless, the results forthcoming from this study of the progressive thermal change in the uppermost waters in a sector of arc 125° and radius of about 36 miles from Aberdeen (see

Figure 1. The Regions studied.

Figure 1) may well be worth further consideration in conjunction with their own material from the same region by planktologists particularly. The question raised by T å n i n g (1950), for instance, of the probability of the number of vertebrae being dependent upon thermal environment during the embryonic stage of a species, or of some species, would appear to be one on which the concept of accumulated temperature in the

sea may have a practical bearing. Moreover, it is conceivable that similar investigations in respect of intermediate and especially bottom waters in fishery regions, and in respect perhaps also of salinity as well as temperature, may contribute materially to the solution of biological problems concerned with the occurrence, abundance, development, and growth of fishes.

Quoting from *The Meteorological Glossary* (1930), "the term Accumulated Temperature is used to describe the excess or defect of temperature in relation to a selected base level, prevailing over a more or less extended period of time, e.g., a day, week, month, or year. The aggregate areas above and below the selected base line bounded by (1) a curve showing the variation of temperature with time, (2) the base line, and (3) the two ordinates from the base to the curve at the beginning and end of the period of time considered, are measures of the accumulated temperature above or below that base line. Values of accumulated temperature are intended to afford a better means of tracing the influence of temperature on crops during critical periods of their growth than mean temperature, the variations of which from year to year are not so marked. Accumulated temperature is expressed in day-degrees, a day-degree Fahrenheit signifying 1°F. of excess or defect of temperature above or below the selected base line extended over a period of 24 hours . . . . . The base temperature adopted by the Meteorological Office is 42°F. as being nearly equivalent to 6°C., the temperature considered by several Continental investigators to be the critical value above which the growth of vegetation in a European climate commences and is maintained."

The central idea above is that of a critical temperature at which the natural organic processes of growth and development are in the neutral inhibitory stage between acceleration and, if not retardation, at least dormancy. This critical temperature may not, of course, be the same for all species of phyto- and zoo-plankton in the sea, nor, on the average, may it be of the same magnitude as that selected for air temperature in relation to soil crops and cereals, but for lack of more specific knowledge on the point, the temperature of 6°C. has been adopted as the base line in the following.

With its relatively much greater abundance of observational data, there are, in meteorology, alternative methods for computing accumulated temperature. The excess or defect above or below the critical level can, for example, be integrated on thermograph records. A similar method seems for the present, on account of the relative scarcity of material, to be the only one directly applicable to the investigation of accumulated temperature in the sea, the derivation of formulae, as in meteorology, for computing accumulated temperature from daily values of maximum and minimum temperature, or even weekly values, unless of course these are read off from thermographs, being out of the question.

Progressive temperature curves for the selected region and for the whole or a part of each year from 1925 to 1937 inclusive, 1939, and 1947 to 1950, were obtained, as in Figure 2, from the records of Scottish

research vessels and fishery protection cruisers, by tracing a smooth curve of best fit through the actual observations of temperature, plotted against calendar time on millimetre-squared paper. The plots of research vessel temperature observations are those of the means between readings at the sea surface and at 10 metres' depth, while those of the fishery cruiser records, used, where available, chiefly to supplement plots about the earlier and more significant parts of the curves, are the Centigrade equivalents of registrations on the Fahrenheit scale. Observations for 1938 in the region dealt with are almost entirely lacking, hence no curve is attempted.

Although reasonably well authenticated in their earlier, more important parts, the curves are on the whole only approximately reliable on account of the comparative meagreness of the observations. The latter are represented by the small crosses on the diagram. The curve for 1950 is more firmly supported than the others by the relatively greater number of observations which were deliberately planned for the purposes of this investigation. The 6°C. base line for each year is represented by a broken horizontal line with the appropriate year indicated on each.

To include all the curves, only that for 1936 requiring to be extended arbitrarily a little to the left to comply in this respect, the basic date selected from which to commence the measurement of accumulated temperature for each year is 20. February, this date also being advantageously near to the minimum of each curve. In Table I are given, in day-degrees Centigrade, first, the increment for each 10-day period following 20. February, and, second, below this number, the successive measures of accumulated temperature. These measurements were made by planimeter, evaluating the areas contained by the base-line temperature of 6°C., the ordinates representing the terminal dates of each 10-day interval, and the temperature curve.

We have thus, from 20. February in each year, material for 18 years in two groups of 13 (1925—1937) and 4 (1947—1950) consecutive years, and one singular year, 1939.

The feature common to all eighteen curves is the rise, with varying gradient, from a minimum, which is represented or implied, to a maximum, again in some cases only implied. Both the magnitudes and the incidence of minima and maxima, however, as well as the gradient between them, vary from year to year. The practical application of the concept of accumulated temperature would seem to provide a means of arriving at an integrated quantitative evaluation of the resultant effect of these several variations taken together.

It is at once apparent from Table I that the above 18 years fall into two groups according as they begin with positive or negative temperature accumulation, thus:—

Accumulation													
+ ve	1925	1927				1932	1934	1935	1936	1939			1950
— ve		1926	1928	1929	1930	1931	1933				1937	1947	1948	1949

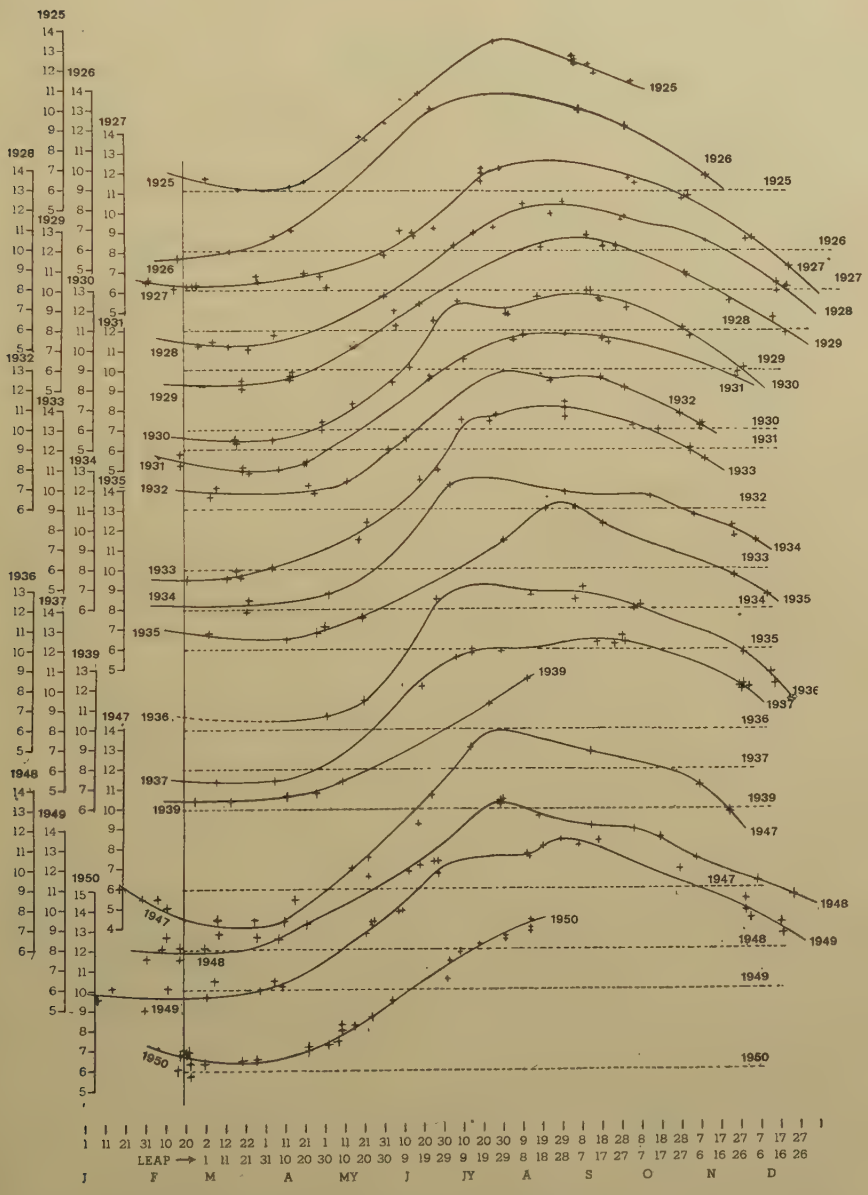

Figure 2. Annual Sea Surface Temperature Curves 1925—1939 (except 1938), 1947—1950, for Sea Area off Aberdeen.

Table I. Incremental and Integral Measures of Accumu
Ten-Day Period

Year	Day/Month 1/3 2/3	11/3 12/3	21/3 22/3	31/3 1/4	10/4 11/4	20/4 21/4	30/4 1/5	10/5 11/5	20/5 21/5	30/5 31/5	9/6 10/6	19/6 20/6	29/6 30/6	9/7 10/7
1925	*5*	*3*	*1*	*1*	*1*	*2*	*7*	*14*	*22*	*31*	*39*	*47*	*55*	*62*
	5	8	9	10	11	13	20	34	56	87	126	173	228	290
1926	*—3*	*—2*	*—½*	*+1½*	*6*	*12*	*19*	*26*	*35*	*44*	*54*	*63*	*70*	*75*
	—3	—5	—5½	—4	+2	14	33	59	94	138	192	255	325	400
1927	*2*	*2*	*2*	*3*	*4*	*6*	*7*	*10*	*13*	*17*	*22*	*28*	*36*	*44*
	2	4	6	9	13	19	26	36	49	66	88	116	152	196
1928	*—7*	*—8*	*—8*	*—7*	*—6*	*—3*	*—½*	*+3½*	*8*	*14*	*20*	*26*	*34*	*42*
	—7	—15	—23	—30	—36	—39	—39½	—36	—28	—14	+6	32	66	108
1929	*—8*	*—8*	*—8*	*—7*	*—6*	*—3*	*0*	*+5*	*11*	*18*	*25*	*31*	*38*	*44*
	—8	—16	—24	—31	—37	—40	—40	—35	—24	—6	+19	50	88	132
1930	*—5*	*—5*	*—6*	*—5*	*—5*	*—3*	*0*	*+5*	*11*	*17*	*26*	*36*	*50*	*61*
	—5	—10	—16	—21	—26	—29	—29	—24	—13	+4	30	66	116	177
1931	*—7*	*—9*	*—10*	*—11*	*—10*	*—8*	*—4*	*+2*	*8*	*15*	*22*	*29*	*35*	*43*
	—7	—16	—26	—37	—47	—55	—59	—57	—49	—34	—12	+17	52	95
1932	*9*	*8*	*8*	*7*	*8*	*8*	*10*	*11*	*16*	*23*	*31*	*39*	*47*	*56*
	9	17	25	32	40	48	58	69	85	108	139	178	225	281
1933	*—5*	*—4*	*—3*	*—1*	*+1*	*4*	*8*	*12*	*17*	*23*	*30*	*39*	*49*	*64*
	—5	—9	—12	—13	—12	—8	0	+12	29	52	82	121	170	234
1934	*2*	*1*	*2*	*2*	*3*	*4*	*6*	*9*	*13*	*20*	*29*	*40*	*52*	*63*
	2	3	5	7	10	14	20	29	42	62	91	131	183	246
1935	*8*	*6*	*5*	*5*	*5*	*6*	*8*	*12*	*15*	*19*	*24*	*29*	*34*	*39*
	8	14	19	24	29	35	43	55	70	89	113	142	176	215
1936	*6*	*5*	*4*	*4*	*4*	*4*	*6*	*8*	*11*	*19*	*30*	*44*	*60*	*69*
	6	11	15	19	23	27	33	41	52	71	101	145	205	274
1937	*—6*	*—6*	*—6*	*—7*	*—6*	*—4*	*0*	*+5*	*12*	*21*	*31*	*42*	*51*	*55*
	—6	—12	—18	—25	—31	—35	—35	—30	—18	+3	34	76	127	182
1939	*4*	*4*	*4*	*4*	*5*	*7*	*9*	*12*	*16*	*21*	*26*	*31*	*36*	*42*
	4	8	12	16	21	28	37	49	65	86	112	143	179	221
1947	*—16*	*—18*	*—19*	*—19*	*—17*	*—12*	*—5*	*+3*	*11*	*20*	*29*	*39*	*49*	*60*
	—16	—34	—53	—72	—89	—101	—106	—103	—92	—72	—43	—4	+45	105
1948	*—1*	*—1*	*—1*	*+1*	*5*	*10*	*14*	*20*	*25*	*30*	*36*	*42*	*49*	*57*
	—1	—2	—3	—2	+3	13	27	47	72	102	138	180	229	286
1949	*—4*	*—3*	*—2*	*—1*	*+1*	*5*	*10*	*17*	*25*	*31*	*39*	*48*	*57*	*63*
	—4	—7	—9	—10	—9	—4	+6	23	48	79	118	166	223	286
1950	*6*	*4*	*4*	*3*	*5*	*7*	*11*	*15*	*21*	*27*	*34*	*41*	*48*	*54*
	6	10	14	17	22	29	40	55	76	103	137	178	226	280

NB. The lower line of Day/Month entries at the head of the table are those corresponding to leap years.

erature in Day-Degrees Centigrade in each successive
bruary.

Day/Month														
8/8 9/8	18/8 19/8	28/8 29/8	7/9 8/9	17/9 18/9	27/9 28/9	7/10 8/10	17/10 18/10	27/10 28/10	6/11 7/11	16/11 17/11	26/11 27/11	6/12 7/12	16/12 17/12	Year
75 510	*72* 582	*69* 651	*65* 716	*61* 777	*57* 834	*53* 887	— —	— —	— —	— —	— —	— —	— —	1925
79 635	*77* 712	*74* 786	*72* 858	*68* 926	*65* 991	*61* 1052	*55* 1107	*49* 1156	*43* 1199	*35* 1234	— —	— —	— —	1926
64 374	*65* 439	*65* 504	*65* 569	*63* 632	*60* 692	*57* 749	*54* 803	*50* 853	*45* 898	*40* 938	*34* 972	*27* 999	*19* 1018	1927
60 272	*63* 335	*63* 398	*62* 460	*61* 521	*59* 580	*55* 635	*53* 688	*51* 739	*48* 787	*44* 831	*38* 869	*32* 901	*25* 926	1928
58 293	*62* 355	*65* 420	*66* 486	*66* 552	*64* 616	*60* 676	*56* 732	*52* 784	*47* 831	*41* 872	*36* 908	*30* 938	*24* 962	1929
62 364	*65* 429	*67* 496	*68* 564	*68* 632	*66* 698	*63* 761	*59* 820	*54* 874	*48* 922	*41* 963	*34* 997	*26* 1023	— —	1930
56 253	*58* 311	*58* 369	*58* 427	*57* 484	*55* 539	*53* 592	*51* 643	*48* 691	*45* 736	*41* 777	*37* 814	— —	— —	1931
69 469	*68* 537	*66* 603	*66* 669	*66* 735	*63* 798	*59* 857	*55* 912	*50* 962	*45* 1007	*39* 1046	— —	— —	— —	1932
80 466	*81* 547	*81* 628	*81* 709	*79* 788	*76* 864	*73* 937	*69* 1006	*65* 1071	*59* 1130	*53* 1183	— —	— —	— —	1933
64 442	*61* 503	*60* 563	*58* 621	*57* 678	*57* 735	*58* 793	*56* 849	*52* 901	*48* 949	*44* 993	*41* 1034	*36* 1070	— —	1934
58 369	*67* 436	*72* 508	*72* 580	*67* 647	*60* 707	*56* 763	*53* 816	*49* 865	*45* 910	*42* 952	*37* 989	*32* 1021	*26* 1047	1935
71 489	*69* 558	*69* 627	*69* 796	*68* 864	*65* 929	*62* 991	*58* 1049	*54* 1103	*51* 1154	*47* 1201	*42* 1243	*36* 1279	*27* 1306	1936
60 361	*61* 422	*61* 483	*64* 547	*65* 612	*65* 677	*63* 740	*60* 800	*57* 857	*54* 911	*50* 961	*45* 1006	*38* 1044	— —	1937
61 384	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —	1939
78 334	*76* 410	*73* 483	*71* 554	*68* 622	*66* 688	*64* 752	*61* 813	*59* 872	*54* 926	*47* 973	*37* 1010	— —	— —	1947
72 496	*69* 565	*65* 630	*63* 693	*61* 754	*61* 815	*59* 874	*57* 931	*51* 982	*46* 1028	*42* 1070	*38* 1108	*35* 1143	*31* 1174	1948
66 483	*68* 551	*73* 624	*75* 699	*71* 770	*68* 838	*63* 901	*59* 960	*55* 1015	*51* 1066	*47* 1113	*43* 1156	*38* 1194	*33* 1227	1949
70 475	*74* 549	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —	1950

Among the years showing positive accumulation from 20. February onwards, acceleration of this accumulation was greatest in 1932, and in this respect the year 1932 maintained its lead, as it were, for a longer period than any other year of the group in relation to another, namely until towards the end of June. At the corresponding date, however, the years 1925 and 1950 had evidently accumulated greater warmth than 1932 despite slower rates of acceleration to begin with.

In descending order of acceleration during the first four 10-day periods, the years arrange themselves thus:—

1932, 1935, 1936, 1950, 1939, 1925, 1927, 1934.

By the end of the fifth 10-day period, however, 1925 had ceded place in the above order to 1927, although the positions reverted again after the eighth period, i.e., after 11. May. Again, by the sixth period — the end of the third week of April — 1950 and 1939, in that order, superseded 1936. And so on, until, by the end of the month of July, the years fall into quite a different order, as follows:—

1925, 1936, 1950, 1932, 1934, 1939, 1935, and 1927.

Thus, from material set out as in Table I, it is possible for a given region to compare quantitatively the thermal state of one year with that of another, and with those of other years, on any date throughout the year, a matter surely of some consequence during the important spawning and larval stages of species.

Turning now to the group of years which commence with negative temperature accumulation relative to the basic temperature of 6°C., 1947 is obviously the most outstanding in so far as its negative accumulation, besides, as at 1. March, being of the greatest magnitude among those recorded in Table I, continued thereafter to increase until the end of April, and was only neutralized in the fourth week of June. Increasing negative accumulation until the end of April, although in lesser degree than in 1947, occurred also in 1928, 1929, 1930, 1931, and 1937. In descending order the more highly negative years range as follows:—

1947, 1931, 1929, 1928, 1937, 1930,

and the negative accumulations of these years were, by Table I, neutralized approximately on the following dates:—

1947	1931	1929	1928	1937	1930
20.	12.	1.	5.	29.	28.
June				May	

In relation to these dates, consider the four remaining negative years. 1926 and 1948 were negative only until the end of March, 1949 until about 25. April, and 1933 until the end of April. There is thus a considerable difference in the average duration of negative conditions as between these two groups of years, an interval of one month intervening between the latest date of the second group and the earliest date of the first.

Nor is it the case, as might perhaps be expected, that the years of

negative accumulation to start with invariably continue throughout the summer to lag behind those years recording positive accumulation from the beginning. The group of the more highly negative years certainly does so until the end of August, but by the end of September, one of these years, namely 1930, was at least on a par with the positive year 1927, if not indeed slightly above it. On the other hand, the secondary group of four somewhat less markedly negative years initially had all of them by the end of July an excess of accumulated temperature over one or more of the positive years. In fact, 1926 superseded at this time the positive year with the highest temperature accumulation at the end of July, namely 1925. Similarly, 1948, second in descending order at the end of July in the list of the four secondary negative years, superseded 1936, the second positive year at this time, and so on, and these relationships continued almost to the end of September.

Other matters of interest and of apparent concern to marine biologists are doubtless deducible from the figures of Table I, the variation from year to year, for example, in the period of time covered by, and the calendar incidence of, specific increments of accumulated temperature from a given base temperature, as enters, for instance, into the questions of the hatching periods of fish eggs and of the development periods of larvae. Perhaps sufficient has been demonstrated, however, to indicate the potential value of such researches as the foregoing, applied to other regions and depths as has already been suggested.

In conclusion, and with reference to Figure 2, attention may be drawn to the apparent appositeness of 6°C. as a base temperature, at least for this particular investigation of the uppermost waters. It seems doubtful whether another base temperature would so clearly differentiate one year from another, especially in their earlier months to May or even June, or July.

Sommaire.

On a démontré ci-dessus, par example retiré des observations de température pour les eaux supérieures de la Mer du Nord dans la région d'Aberdeen pendants les années 1925 à 1950, l'application aux recherches marines d'une nouvelle donnée hydrographique. De la science météorologique on a emprunté le concept de température accumulée avec lequel plusieurs auteurs ont demontré autrefois la corrélation de produits céréals et d'autres récoltes. On a suggéré que cette donnée de température accumulée, appliquée à la mer, et évaluée par l'intégration graphique d'une courbe annuelle de température, fournit probablement un moyen meilleur que les observations actuelles de température, d'associer les procès organiques dans la mer avec sa chaleur effective. Il est aussi suggéré que la même donnée soit appliquée aux eaux intermédiaires et de fond dans les régions de pêcheries pour l'investigation des problèmes biologiques avec lesquelles la chaleur de la mer est évidemment, ou presque seul probablement, associée.

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On the Cooling of Sea Water and the Influence of the Water Heat Content on the Time of Freezing in the Archipelago and North Baltic.

By

Heikki Simojoki.

THE observations used to illustrate the thermal conditions in the sea water were obtained from the following hydrographical stations:— Jungfruskär (60°08′N., 21°04′E.), Lohm (60°07′N., 21°41′E.), Utö (59°47′N., 21°22′E.), and Bogskär (59°31′N., 20°23′E.). The first two stations are situated in the Archipelago, the latter two in the north Baltic. The temperature soundings were made three times a month, at 10-day intervals. The observations cover the years 1921—46; for Bogskär, however, the period is 1901—13.

Table 1. Temperature of the Water Column, °C.

	Mean Maximum		Mean, for Homothermal Column		Mean Minimum	
Jungfruskär (0—40m.)	12·9°	29.VIII	10·0°	13.X	—0·1°	16.II
Lohm (0—50 m.)	12·7°	2.IX	9·1°	21.X	—0·0°	23.II
Utö (0—90 m.)	8·8°	15.IX	5·7°	26.XI	0·4°	5.III
Bogskär (0—150 m.)	5·9°	28.IX			1·6°	16.III

Table 1 gives, for a water column reaching from the surface to the bottom, the average maximum temperatures, the average temperatures of the water when the column is approximately homothermal, and the average minimum temperatures, together with the corresponding average dates of occurrence. The table shows that in the Archipelago region both the heating and cooling of the water are considerably greater than in the Baltic. This also appears from the values of the yearly heat budget, that is, the overall loss or gain of heat, by the water column in the course of the year.

Table 2. Heat Budget for the Water Column, Kg. cal./sq.cm.

	Mean	Maximum	Minimum
Jungfruskär	52	64	40
Lohm	64	75	46
Utö	76	96	47
Bogskär	63	87	42

According to the above values, the heat budget is greater at Utö than in the Archipelago and the open parts of the north Baltic. It seems that for the deep water just beyond the outer skerries heat transference to the atmosphere is greater than farther out to sea. The values of the heat budget were calculated from the difference between the yearly maximum and minimum heat supplies of the whole water column and the results are therefore greater than those calculated from smoothed average values.

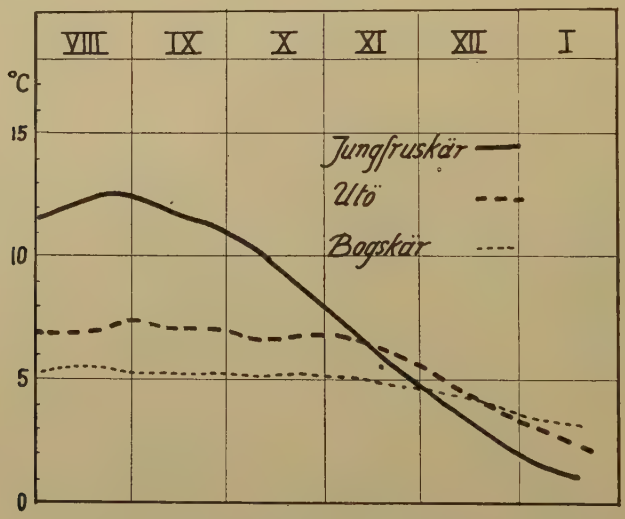

Figure 1. Average temperature of the water column at Jungfruskär, Utö, and Bogskär.

Figure 1, which represents the course of the average temperature of the water column at Jungfruskär, Utö, and Bogskär, shows that the cooling in the Archipelago (Jungfruskär) proceeds regularly, while, on the contrary, in the north Baltic (Utö and Bogskär) irregularities may be observed in the course of the temperature decrease owing to advective heat variations in the sea water.

In the study of the relation between date of freezing and water temperature, the dates of appearance of the following ice situations were considered:—

1. The region of the islands near the continental coast is covered by

fast ice and a narrow ice border encloses the islands of the Archipelago, but the great open areas of water in the Archipelago are ice free,

2. A thin ice bridge connects the Åland Islands to the continent,
3. Fast ice reaches Utö.

These ice situations correspond most closely to J u r v a' s ice phases S_3^d, S_6^d, S_8^d.

The importance of the water's maximum temperature in relation to the time of freezing is slight. The probability that a maximum temperature higher than normal corresponds to a freezing later than normal is 46 % for the phase S_3^d, 62 % for the phase S_6^d, and 63 % for the phase S_8^d. The deviations in individual years, however, are considerable; for instance, in autumn 1939 the maximum temperature of the whole water column was 3° higher than normal, but phase S_6^d nevertheless appeared 29 days earlier, while in autumn 1942 the maximum temperature of the water at Utö was 3° lower than normal, but the ice did not reach Utö during the winter.

Examination of the dependence of freezing time on the temperature when the water column is approximately homothermal reveals a somewhat higher correlation, though considerable deviations still exist. For every winter in which phase S_6^d did not appear, the average water temperature was higher than normal whenever the water was homothermal. In winters when phase S_8^d was not reached the deviation of water temperature from normal was positive in 5 cases and negative in 3 cases.

The average water temperatures at the times of establishment of the above-mentioned ice phases and their average times of appearance were:—

S_3^d	30.XII	2·3°C.	Jungfruskär
S_6^d	28.I	0·3°C.	Jungfruskär
S_8^d	5.II	0·8°C.	Utö

The greatest observed positive deviations from these values are 1·3, 0·8 and 0·9° respectively. Whenever the water temperature is higher than these values, no establishment of the ice phases in question can be expected.

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Ice in the Baltic and the Meteorological Factors.

By

Erkki Palosuo.

THE development of ice conditions is usually examined in relation to meteorological factors, especially air temperature and wind. In the present paper, in which this question is investigated for the Baltic region, the weather observations from Mariehamn are used.

For the study of the freezing of the sea water I have chosen certain typical ice conditions, which occur in different winters in as similar a form as possible and of which the times of occurrence can be readily fixed. The first of these ice conditions selected is the formation of the ice bridge[1]) to Åland (Fig. 1). This happens nearly every winter, but of the 25 winters here studied, i.e., 1926 to 1950[2]) the winters 1938 and 1939 were so mild that no ice bridge was formed. In the winter 1930 ice sludge was present in the region mentioned on 17. March, but it disappeared two days later when the wind rose. This occurrence is disregarded, however, because it has no effect on the final conclusions.

Other stages chosen for the region of the archipelago and the Baltic are the freezing of the Vidskär Sea, and also the spreading of the ice from Utö towards the northern Baltic. Those cases in which ice appeared off Utö after drifting from other places — for instance, the Gulf of Finland — have not been taken into consideration.

The extension of the ice edge to Bogskär in the Baltic was established chiefly by information from ships. In extraordinarily rigorous winters, when the ice edge moved far to the south, the times at which it appeared off the southern part of Gotland and at which the Baltic Sea was entirely frozen over were fixed by observation from aeroplanes.

If we study the course of the air temperature at Mariehamn, we note that in the early part of winter solitary frost days or short frost periods occur. During these times, ice may form in shallow bays and

1) The bridge extends from the mainland.
2) By "the winter 1926" is meant the winter 1925/26.

close inshore, but in the milder days intervening between these periods the ice disappears, at least to some extent, so such preliminary frosts can be disregarded. (See Fig. 2.)

In the study of air temperature, the starting point selected is the appearance of the 0°-isotherm. This date is defined, from suitably arranged 5-day mean values, as the beginning of the period of continuous frost in the winter in question or the time at which the frost periods began to be more severe than the intervening milder periods.

In exceptionally rigorous winters, such as 1942, the frost period was almost continuous during the whole winter until spring. In other severe winters, such as 1948, although the frost was almost continuous, in midwinter it was not as severe as in those winters of which 1942 is an example. In mild winters, such as 1944, frost occurred for short periods only.

Figure 1. Some typical ice situations in the Baltic. Explanation: A = formation of the ice bridge to Åland; V = freezing of the Vidskär Sea; U = extension of the ice from Utö towards the northern Baltic; B = ice edge at Bogskär; G = ice edge off the southern part of Gotland; D = freezing of the open sea in the Baltic.

Table 1. The number of frost days and the total daily m of appearance of the 0°-isotherm

	Winter	Previous frost t	Previous frost n	0°-isotherm date	A = Åland Date	A = Åland t	A = Åland n	V = Vidskär Date	V = Vidskär t
I	1942	—32	11	1.XII	30.XII	—115	24	5.I	—121
	47	—12	7	10.XII	13.I	—91	25	24.I	—128
	40	—	—	8.XII	6.I	—105	26	17.I	—174
	41	—15	7	9.XII	3.I	—109	21	15.I	—175
	29	—5	4	12.XII	18.I	—113	28	10.II	—236
	26	—15	11	22.XI	26.XII	—145	27	9.I	—170
II	1948	—19	10	13.XII	9.I	—131	23	25.I	—205
	28	—	—	9.XI	28.XII	—172	41	19.I	—265
	46	—3	6	6.XII	16.I	—99	29	21.I	—113
	32	—2	3	7.XII	10.II	—128	31	10.II	—128
	36	—15	11	5.I	10.II	—84	24	15.II	—117
	31	—	—	14.XII	22.I	—116	35	21.I	—114
III	1937	—1	1	16.I	29.I	—57	14	9.II	—100
	33	—5	6	11.I	15.II	—103	26	25.II	—188
	27	—20	10	13.XII	22.I	—120	33	20.II	—181
	50	—11	5	28.XII	18.I	—158	21	15.II	—234
	45	?	?	5.I	30.I	—66	19	18.II	—116
	34	—24	12	6.XII	11.III	—132	39	11.III	—132
	35	—	—	23.XII	7.II	—98	33	—	—
	43	—1	2	25.XI	24.I	—138	39	—	—
IV	1949	—17	15	16.I	9.III	—95	26		
	44	—3	2	30.XII	27.II	—74	31		
	38	—2	2	29.XI	—	—	—		
	39	—	—	16.XII	—	—	—		
	30	—6	5	28.I	—	—	—		
I	Average			5.XII	6.I	—113	25	19.I	—167
	Average variability					11	2		29
	Percentages					10	8		17
II	Average			9.XII	21.I	—122	31	29.I	—157
	Average variability					22	5		52
	Percentages					17	17		33
III	Average			24.XII	4.II	—109	28	21.II	—158
	Average variability					28	8		43
	Percentages					25	29		27

eratures <0° C. at Mariehamn reckoned from the date ccurrence of various ice situations.

Utø (10 sm)		B = Bogskär			G = Gotland			D = Baltic			
t	n	Date	t	n	Date	t	n	Date	t	n	
—145	32	20.I	—279	43	30.I	—457	53	6.II	—540	60	
—157	35	12.II	—300	51	21.II	—372	60	24.II	—410	63	
—190	35	1.II	—341	50	8.II	—488	57	26.II	—678	64	
—297	41	30.I	—375	47	21.II	—554	69	24.II(?)	—571	72	I
—236	52	15.II	—295	57	28.II	—439	70	—	—	—	
—170	40	14.I	—249	51	—	—	—	—	—	—	
—241	42	18.II	—313	54							
—377	83	—	—	—							
—200	56	—	—	—							
—233	56	—	—	—							II
—130	30	—	—	—							
—180	43	—	—	—							
—226	49										
—240	46										
—	—										
—	—										
—	—										III
—	—										
—	–										
—	—										
											IV
—199	39	31.I	—307	50	16.II	—454	62	20.II	—550	65	
45	7		37	3		41	6		75	4	I
23	22		12	6		9	10		14	6	
—227	52										
57	13										II
25	24										
											III

For each winter the number of frost days and the total daily mean temperatures <0°C. were computed over the period from the time of occurrence of the 0°-isotherm until the establishment of the ice situations described (Table 1). For the exceptionally severe winters, classified as group I, in which the ice reached its greatest extent, the conditions are relatively uniform. As some writers have already pointed out, this seems to be due to the fact than in these winters the frost was almost continuous. As regards the ice bridge to Åland, considerable abnormality in the number of frost days occurred during the winter 1941, when the water froze 4 days earlier than the average. But in this case the frost during the two days preceding the freezing of the water was sharper than usual, as is shown below. As regards the freezing of the Vidskär Sea and the extension of the ice from Utö towards the northern Baltic, the abnormalities are more important, for in such border regions the fluctuations of water temperature are more considerable than in the inner skerries or well out at sea. Conditions as regards the ice edges off Bogskär and Gotland were more uniform.

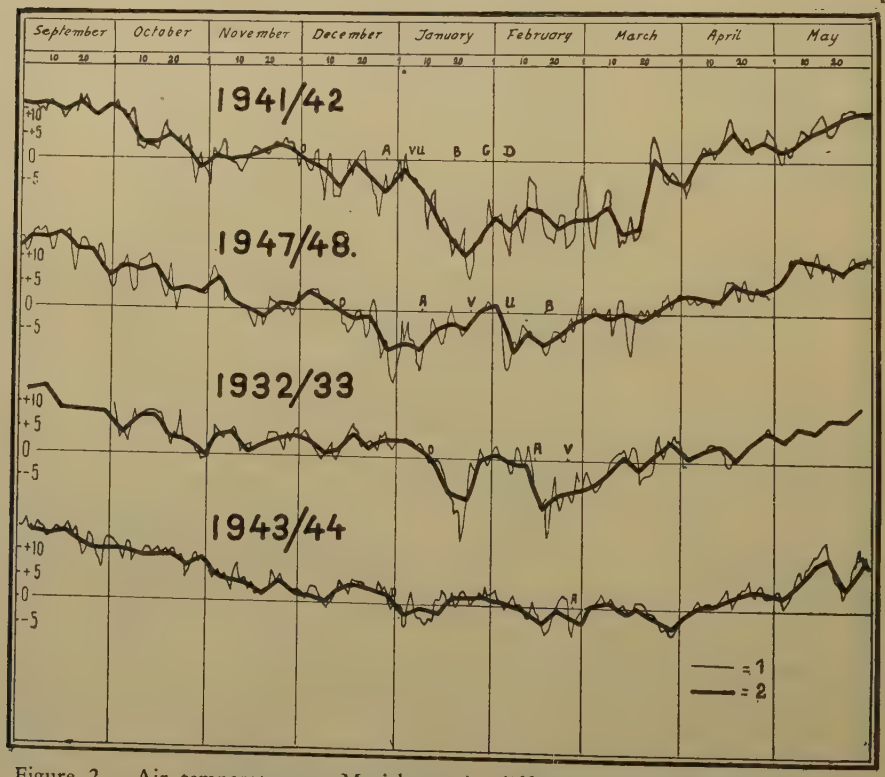

Figure 2. Air temperature at Mariehamn in different winters. Explanation: 1 = curve of daily average temperature; 2 = curve of 5-day mean values; 0 = date of appearance of the 0°-isotherm. A = formation of the ice bridge to Åland, etc.

In the groups which cover the milder winters the number of frost days was greater than in exceptionally hard winters. In the milder winters the frost was often not continuous, being interrupted some times by long mild periods between the frosts. For example, in winter 1928 the 0°-isotherm occurred as early as 9. November and from then to the arrival of the ice bridge at Åland there were 41 frost days, whereas in winter 1937, the 0°-isotherm did not appear until 16. January, and there were no mild intervening days thereafter, so that the number of frost days was only 14. In those exceptional winters, the water temperatures at the time of the appearance of the 0°-isotherm were also exceptional (see below).

The effect of the wind on the freezing of the water is twofold. On the one hand, the wind causes a rapid cooling of the water and thus

Table 2. The average velocity of the wind at Mariehamn from the appearance of the 0°-isotherm until the formation of the ice bridge to Åland.

	Winter	Mean wind for the total period m./sec.	Mean winds, for frost days m./sec.	Number of frost days
I	1942	1·8	1·9	24
	47	5·6	5·1	25
	40	3·7	3·4	26
	41	3·1	2·9	21
	29	5·0	4·4	28
	26	2·8	2·0	27
II	1948	3·0	2·8	23
	28	3·2	2·8	41
	46	5·4	4·9	29
	32	5·0	4·4	31
	36	4·9	4·0	24
	31	3·7	3·5	34
III	1937	7·4	7·4	14
	33	3·9	3·5	26
	27	3·6	3·1	33
	50	2·5	2·5	21
	45	2·0	1·7	19
	34	4·8	4·4	39
	35	4·2	4·3	33
	43	3·3	4·4	39
IV	1949	5·5	4·8	26
	44	4·7	3·5	31
	38	—	—	—
	39	—	—	—
	30	—	—	—
	Mean	4·4	3·6	28

Table 3. The number of frost days grouped according to average wind velocity.

Mean wind m./sec.	2	3	4	5	>5
	24	21	26	28	25
	21	27	34	29	14
Number	19	23	26	31	—
of	—	41	33	24	—
frost days	—	39	33	39	—
	—	—	—	26	—
	—	—	—	31	—
Mean	21	30	31	30	20

facilitates freezing. On the other hand, the wind roughens the surface of the water, and this mechanical effect counteracts the formation of ice. For a study of the influence of the wind on the interval of time elapsing between the appearance of the 0°-isotherm and the arrival of the ice bridge at Åland, the average velocity of the wind was computed from the daily average values at Mariehamn both for the whole period and also for the frost days alone (Table 2). Grouping these values according to the average velocity of the wind (Table 3), we see that the number of frost days is, as a rule, smaller during periods of weak winds; that is to say, a period of calm sea in the beginning of winter seems to facilitate the freezing of the water. A closer examination of the figures shows that the maximum number of frost days is associated with an average wind velocity of 4 m./sec. When the velocity of the wind is greater than this, the number of frost days apparently tends to decrease. The number is least (14) for winter 1937, when the average velocity of the wind was 7·4 m./sec. The statistics are unfortunately too scanty for a closer scrutiny.

As already mentioned, frost days with calm weather favour the freezing of the water. If we study the conditions prevailing on the day of the establishment of the ice bridge to Åland, and on the preceding days (Table 4), we see that as a rule the water froze when the frost intensified and the wind dropped. In winter 1940, when the number of frost days was only 21, on the two days preceding the formation of the ice bridge, a frost of —18°—19°C. occurred.

In a consideration of the initial phases of ice development, daily *minimum* temperatures would seem to be more suitable than the daily

Table 4. The average air temperature and wind velocity at Mariehamn on the day of formation of the ice bridge to Åland (= 0) and succeeding days.

	Days before								Days after		
	—7	—6	—5	—4	—3	—2	—1	0	+1	+2	+3
Temperature of air (°C.)	—3·4	—2·0	—3·2	—3·8	—5·0	—5·7	—7·4	—7·5	—4·5	—3·7	—3·3
Wind m./sec.	3·3	4·3	4·4	4·4	3·7	3·7	3·0	2·2	3·8	4·1	4·4

means. This kind of data is also to be preferred in studies of the freezing of lakes, shallow bays, etc. For this purpose we may reckon the number of days needed for ice development as the number of days with minimum air temperatures under a certain value (— 3°C.).

In this connexion the effect of water temperature in promoting or delaying freezing may be mentioned. If we study the surface water temperature at Jungfruskär on the day immediately preceding the appearance of the 0°-isotherm (Table 5), we see, for instance, that at this time in the winter 1928 the water temperature was 2·5° *above* the average value, which is associated with 41 frost days up to the formation of the ice bridge to Åland. Whereas in winter 1937 the water temperature was 1·2° *below* the average value and the corresponding number of frost days was only 14. The surface water temperature

Table 5. The surface water temperature and the temperature of the water column at Jungfruskär on the day of appearance of the 0°-isotherm.

	Winter	0-isotherm Date	Surface water temperature	Heat content of water cal./cm².	Number of frost days
I	1942	1.XII	+3·0°C.	$12{\cdot}7\times10^3$	24
	47	10.XII	+3·6	17·2	25
	40	8.XII	+4·1	17·3	26
	41	9.XII	+3·1	17·1	21
	29	12.XII	+3·7	21·1	28
	26	22.XI	+3·0	15·4	27
II	1948	13.XII	+3·0	14·1	23
	28	9.XI	+5·6	24·0	41
	46	6.XII	+1·3	14·7	29
	32	7.XII	+2·5	16·6	31
	36	5.I	+3·5	12·9	24
	31	14.XII	+2·3	12·8	35
III	1937	16.I	+1·9	9·5	14
	33	11.I	+2·1	10·7	26
	27	13.XII	+3·2	13·0	33
	50	28.XII	+3·1	15·5	21
	45	5.I	+2·8	12·2	19
	34	6.XII	+1·5	12·8	39
	35	23.XII	+4·9	20·2	33
	43	25.XI	+4·0	19·1	39
IV	1949	16.I	+1·6	7·1	26
	44	30.XII	+3·2	14·6	31
	38	29.XI	+5·5	24·4	—
	39	16.XII	+2·8	22·6	—
	30	28.I	+2·7	10·7	—
	Mean	5.XII	+3·1	15·5	28

observations are made in the vicinity of the coast, and in order to render these comparable with deep water conditions, I have estimated the heat content of the water column for a position at which the depth of water is 40 m. As observations have been made at about 10-day intervals, the dates of the occurrence of the 0°-isotherm were obtained by linear interpolation.

In the foregoing study, the intensity of the frost is defined by the number of frost days, and the strength of the frost has been disregarded. An alternative method would be the classification of frost days by the degree of frost, for 5° intervals, for instance, and the effect of each group could be examined separately. This preliminary examination shows, however, that the use of the number of frost days in ice investigations yields good results, sufficient for practical needs.

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Horizontal Plankton Hauls.

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Introduction.

For many investigations an estimate of the plankton population density at different levels in the water column is wanted. This has been obtained from either a set of "sectional" vertical hauls or a series of horizontal hauls. The former method, which has been, and still is, extensively used, and which under certain circumstances may be the only practicable method, has a number of marked disadvantages; in addition to technical difficulties (Barnes, 1949), recent statistical work has emphasized that, as a result of changing position during sampling, the small-sized sample obtained in this way from any given level is often inadequate to give a useful estimate of the plankton at that level and over an area comparable with that actually sampled. Horizontal hauls, in which different levels are sampled simultaneously over a large area by the use of a number of nets on a single warp, are to be preferred and this method has been adopted by some workers, notably Russell (see below) and Gardiner (1933). It is necessary to know the depth at which catches are taken with such hauls and attention to depth determination has been particularly stressed by Russell, whilst Hermann (1949) has recently described a new depth-gauge for such work.

Russell and Colman (1931) and Russell (1926) have given details of the method in which the angle at which the towing warp enters the water is observed. As far as possible this angle is kept constant by regulating the speed of the ship, and the depth at which the nets fish is thereby controlled. Preliminary calibration by means of a depth recorder enables the depth equivalent to a given wire angle and warp out to be found. However, due to vibration and motion of the

ship it is difficult, particularly as working conditions deteriorate, to keep an accurate check on the wire angle with the simpler instruments and a wire angle indicator designed to eliminate such difficulties has been described by Moore (1941). As the amount of warp used is increased the method becomes less sensitive for controlling depth under poor working conditions; a preliminary study showed the method to be far from satisfactory, even at moderate depths.

The Paravane Technique.

It would clearly be of advantage to have a device in which depth of nets at varying speeds was automatically kept constant and some form of paravane technique such as has been extensively employed by Hardy (1944) in the development of his plankton recorders and indicators seems to be indicated. However, it would appear an advantage to be able to control either a number of nets or a single net without each being fitted with a paravane. Gardiner (loc. cit.) realized the possibilities of the method and made reference to the submarine sentry (Wharton and Field, 1920).

The modern development of the submarine sentry is the kite-otter multiplane which has been extensively used in minesweeping work. With this kite-otter multiplane it has been shown that it is possible to control accurately nets as large as the 2-metre stramin over considerable variations in speed independtly of weather conditions and without continuous attention.

The multiplane consists of a trapezoidal frame, with a series of transverse curved plates set at an angle, the side plates of the frame being inclined, so that when the multiplane is used as described below they have a rudder action and consequently give lateral stability. When used as a depth-keeping device for nets it is rigged on a three-point tow; in these experiments it has been towed from the trawl warp passed over a gallows sheave. Attachment of the towing warp to the multiplane slings has been made directly by a shackle. For extensive use some form of shock absorber between warp and multiplane, such as is used in the Hardy plankton recorder, would be advisable, since the strain appears to be greatest at this point. The standard multiplane is rather heavy and a smaller and lighter one, used with a lighter warp, could no doubt be developed.

The method of working is as follows:— the multiplane, attached to the trawl warp and worked from the after gallows on the starboard side is lowered just below the surface. The ship is then turned to starboard and as the multiplane swings clear a small amount of warp is run off. The net (or nets) are then attached at sufficient distance from the multiplane to prevent the two fouling and the desired amount of warp is run off. For testing and calibrating, the depths of the nets were determined by means of a Barr and Stroud depth recorder fastened to the net bridles. The effectiveness of depth control obtained may be

illustrated by reference to the results with the 1-metre stramin, a depth record for which is shown in Figure 1.

With 30 feet of warp out a depth of 20 feet was obtained at an engine speed of 2·9 knots with the net attached just above the paravane. Increasing the engine speed to 4·5 knots, a change in speed of about 1½

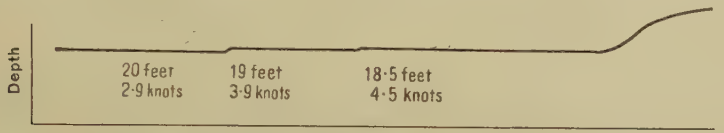

Figure 1. Depth record with 1-metre stramin attached, showing constant depth at given speed and small changes on increasing the speed.

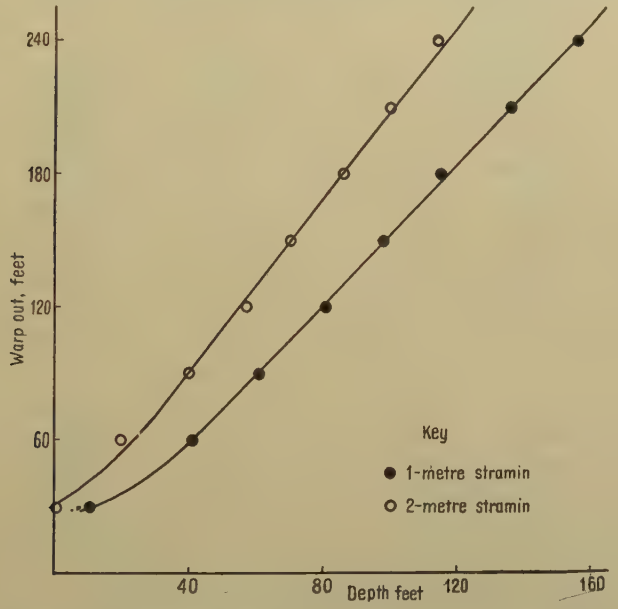

Figure 2. Calibration curve for 1- and 2-metre stramin nets.

knots, only lifted the net by 1·5 feet. The change of depth with the variation of speed normally encountered in towing such nets would clearly be negligible. (The short warp results are quoted since small changes in depth are more easily demonstrated on the depth records taken at shallow depths.) Figure 2 shows a calibration curve for the 1- and 2-metre stramin nets, when both were attached 2½ fathoms above the multiplane.

The use of the technique may be illustrated by reference to three series of plankton hauls taken with small nets. The nets were of coarse mesh, with a mouth filtering-surface ratio of 1 : 4, and probably filtered almost the theoretical quantity of water at all the speeds used.

The first net was attached 2½ fathoms above the multiplane, and with 20 fathoms of warp out, fished at a depth of 14 fathoms. In Series I two nets were attached to the warp 1 metre apart. Four tows were taken as far as possible over the same course and in the same direction at constant speed (2·8 knots), the total time of each haul being 20 minutes. With a haul of this duration and small fishing depth the errors due to fishing during hauling and shooting may be neglected. The usual precautions were taken in removing the catch, which was not sub-sampled for counting. Two groups were counted, copepod copepodite stages and *Sagitta* sp., the mean total catch per net per haul being 63.

The analysis of variance gives, on logarithmic values:—

Source of variation	Degrees of freedom	Sum of squares	Mean square
Main Effects.			
Hauls (H)	3	0·1257	0·0419
Groups (G)	1	0·6460	0·6460
Nets (N)	1	0·0580	0·0580
First-Order Interactions.			
H×G	3	0·0857	0·0286
H×N	3	0·0173	0·0058
N×G	1	0·0091	0·0091
Second-Order Interaction.			
H×G×N	3	0·0497	0·0166
Total	15	—	—

The first-order interactions are not significant (the 0·05 level is accepted througout) nor are the mean squares for hauls and the nets, so that the proportion caught by nets did not vary significantly with the hauls or groups; there was no significant difference between the haul or net totals. There is no indication therefore of any vertical gradient of the population. The mean square for H×G is not significant so that the proportion of the groups did not change with the hauls, this together with the "constant" haul totals indicating that no change of population had taken place (as far as one can test) during the course of the hauls. The high mean square for G reflects, of course, the fact that the two groups counted were present in different population densities. After pooling the various estimates one obtains for the (logarithmic value) variance of a count of a single group of 0·0247 equivalent to a log standard deviation of 0·1572 or a coefficient of variation of 44 %.

The hauls extended over two hours, and the coefficient of variation is less than that reported for horizontal hauls by other workers (see, for example, Winsor and Clarke, 1940) although it must be noted that the population density in this series was much lower than that obtained in Winsor and Clarke's work.

In Series II paired nets, 1-metre apart, were towed with 63 fathoms of warp out in deep water. The tows were taken with negligible tidal current for a measured distance, the latter being carefully determined by running the same course and observing land marks, at a distance of ½ mile apart. Alternate tows, in the same direction, were done at speeds of 2·8 and 3·2 knots. Since the distance traversed was smaller (7—10 minutes) and the depth of fishing greater than in Series I, errors might arise due to fishing during hauling and shooting if organisms distributed throughout the water column were counted. Only the deep-water forms, *Meganyctiphanes norvegica* and *Euchaeta norvegica* were therefore enumerated, again without sub-sampling the catch. As in Series I no significant difference was found between the nets (positions) or their interactions and the catches of the two nets together have therefore been pooled. The analysis of variance gives then:—

Source of variation	Degrees of freedom	Sum of squares	Mean square
Main Effects.			
Hauls (H)	3	0·0474	0·0158
Species (Sp)	1	0·1681	0·1681
Speeds (S)	1	0·0030	0·0030
First-Order Interactions.			
H×S	3	0·1323	0·0441
H×Sp	3	0·0076	0·0025
S×Sp	1	0·0507	0·0507
Second-Order Interactions.			
H×S×Sp	3	0·0382	0·0127
Total.	15	—	—

None of the first-order interactions are significant so that the proportions of the animals caught did not vary with the hauls or the speeds and the proportion at the two speeds did not vary with the hauls. Again there is no evidence of a changing population during the experiment and no evidence that the speed of tow had any effect on the catch of these species. After pooling the estimates the variance of a single observation of a chosen group is 0·0199, equivalent to a coefficient of variation of 38 %. This analysis has shown that the speed had not affected the catch, but this does not prove conclusively that the level of fishing had been unaltered by the change in speed; this would only become evident if a change in position of the nets caused a different population to be fished.

In Series III the experiments were done off the Arran measured mile. An estimate of the small tidal current was obtained by timed runs and a correction factor applied to the catches. The set-up was as follows:— the two nets were attached to the warp 5 metres apart, the upper net being attached as before so that it could be easily taken off without interrupting hauling. A tow at 2·8 knots was followed by one

at 3·2 knots and these paired tows were duplicated. Two groups were counted, *Sagitta* sp. and copepod copepodites. With a mile tow at 40 fathoms the error of fishing during hauling has been neglected.

The experiments extended over a considerable time and a preliminary analysis was made to determine if any significant population changes were evident. There was no evidence of any such changes, and the paired tows can be considered as duplicates. The analysis of variance therefore is as follows:—

Source of variation	Degrees of freedom	Sum of squares	Mean square
Speeds (S)	1	0·0001	0·0001
Nets (N)	1	0·1156	0·1156
S×N	1	0·0073	0·0073
Residual 1	4	0·0215	0·0054
Groups (G)	1	8·8507	8·8507
S×G	1	0·0324	0·0324
N×G	1	0·1764	0·1764
N×S×G	1	0·0209	0·0209
Residual 2	4	0·1577	0·0357

Now the values are taken to apply to this experiment only. The value for speeds is not significant so that there was no significant difference between the totals at the two speeds. S×N is not significant so that the proportion of all groups caught in the two positions did not change with the speed of the tow. However, the mean square for nets is significant, so that the net totals are significantly different. Now the S×G, N×G, and N×S×G interactions are not significant. The proportions of the groups caught at the two speeds or by the two nets in their different positions did not vary significantly. Now since neither the speed mean square nor the mean squares for interactions containing speed were significantly different, it can be assumed that the change in speed had had no effect on the catch. However, the net totals were significantly different and this together with the above evidence indicates a population density gradient over the 5 metres separating the two nets. Under these circumstances if the speed had changed the position of fishing of the nets the effect would in general be expected to be revealed by the foregoing analysis.

Summary.

The need for accurate depth control in horizontal hauls is stressed.

A technique using a kite-otter multiplane towed on the trawl warp is described, the depth control effected by this device being shown to be adequate.

The results of a series of horizontal hauls are quoted.

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Preliminary Studies of Nanoplankton and Ultraplankton Systematics and Abundance by a Quantitative Culture Method.

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Introduction.

Nanoplankton and ultraplankton investigations were included in programmes of oyster research at the Fisheries Experiment Station, Conway, and the newly-established Fisheries Laboratory, Burnham-on-Crouch, because oyster larvae can ingest nothing larger than about 10 μ and appear to rely upon flagellates for food (Cole, 1936, 1939; Bruce, Knight and Parke, 1940).

These organisms are relatively difficult to investigate because of the difficulty of recognizing them in preserved samples. Little is known about them, and it is sometimes supposed that they are of slight importance because their total mass is thought to be small compared with that of other phytoplankton organisms. This is not invariably true. To judge from results obtained by Harvey (1950) at Plymouth, more than 90 % of the total mass of phytoplankton passed through the meshes (40μ×50μ) of a fine net, throughout most of the year. On the only two occasions for which results are given, about 40 % passed through a Whatman No. 2 filter-paper. Atkins (1945) had suggested that the bulk of phytoplankton production was probably due to autotrophic flagellates rather than to diatoms, since the silica which disappeared from solution was only about 10 % of that to be expected if all the phosphate which disappeared had gone to diatom production.

When nanoplankton is sparse, it is likely to be of especially critical importance. Thorson's recent review showed that planktotrophic larvae relying upon nanoplankton and ultraplankton for food are met with in the development of more than 70 % of all benthic invertebrates. The manner in which the type of larval development of such forms

varies with latitude is strong evidence that the level of ultraplankton production is often a factor limiting their development. Thus, in East Greenland seas only 5 % of benthic invertebrates have a planktotrophic stage, in boreal seas 55—65 %, and in tropical seas 80—85 % (Thorson, 1950). The overwhelming success of the planktotrophic habit in tropical coastal waters must depend on a high level of ultraplankton production. Its comparative rarity in high latitudes is probably due to the food supply there being less dependable. The phenomenon is not likely to be an effect of temperature alone. Lowered temperatures are accompanied by prolongation of larval life in *Ostrea edulis* (Korringa, 1941), but it is uncertain to what extent poorer food conditions contribute to this effect. In boreal seas nanoplankton production is probably greatly influenced by the weather changes which cause temperature fluctuation.

Ultraplankton serves as food for members of the permanent plankton also. Clarke and Zinn (1937) found that *Calanus* sometimes grew rapidly when diatoms were very sparse, and suggested that small flagellates, which were at all times numerous, might be important as food for copepods. Raymont and Gross (1942) showed that *Calanus* grew when fed with pure cultures of flagellates down to less than 2μ in size.

Routine studies of nanoplankton abundances have for some years formed part of investigations into the factors associated with good growth and survival of oyster larvae in the oyster-breeding tanks at Conway and in oyster-producing estuaries of Cornwall and Essex. The standard method used has been to concentrate the water sample quantitatively by filtration through a collodion membrane, and to examine sub-samples of the concentrate in a haemacytometer (Cole and Knight-Jones, 1949). It was soon realized that the majority of the organisms seen were of undescribed species, and as many as possible were isolated in culture for systematic study. An account of some of these, dealing with sixteen new species, is in the press (Butcher, 1951). A brief systematic survey of the organisms observed is given later, for such information as is available on this subject is rather scattered.

The most useful method of isolating organisms in culture was serial dilution of sea-water samples into test-tubes of culture medium. At the suggestion of Dr. H. A. Cole the dilutions were carried out quantitatively according to the method described below, from which it was possible to arrive at estimates of the nanoplankton densities in the sea-water samples.

There appear to be few previous accounts of nanoplankton estimation by culture methods. The only one with which I am familiar is that of Allen (1919). Culture methods offer a possible solution to some of the problems which other methods present. General phytoplankton methods, such as the pigment extraction method, should be supplemented by qualitative examination, for they may be weighted by the presence of a few diatoms so large as to be useless as food for most

plankton animals. Such examination usually requires preliminary concentration of samples, and this presents some difficulty. Centrifuging of living, healthy material is probably ineffective as a method of concentration, since even large diatoms remain suspended (Gross and Zeuthen, 1948). If some method of fixing and staining were evolved, which would enable the smaller organisms to be preserved in a recognizable form, centrifuging or precipitation techniques might be very useful, but at present the only practicable method of concentration appears to be membrane-filtering.

The chief difficulty when making the subsequent haemacytometer counts is recognition. Haemacytometer chambers are too deep for $^1/_{12}$ inch objectives, and with lower magnifications even experienced observers may find it impossible to decide whether a 1μ speck is a blue-green alga, a bacterium, an immobilized flagellate, or a particle of detritus. Such specks are often very abundant. Even the larger ultraplankton organisms are rather difficult to identify. Flagellates soon become immobilized in the bright light of a microscope stage. Cryptomonads lose their characteristic shape and become rounded. It is sometimes difficult to distinguish a *Chlorella* of about 4μ from an immobilized naked flagellate of the same size, but it is important to do so, for the *Chlorella* with its thick cell-wall must be relatively indigestible. Repeated experiments at Conway showed growth of oyster larvae with flagellates as food, but not with *Chlorella* (Cole, 1936; 1939).

A quantitative culture method solves the problem of recognition. To make the dilutions requires care but no experience. It can be done at sea, in quite rough weather, and the dominant organisms can be identified later, in comfort, by an expert, from abundant material. The most important culturing precaution is probably temperature control. It would be most desirable, if not essential, to keep the culture-tubes in a refrigerator, the temperature of which should be varied seasonally to approximate to that of the body of water from which samples are being taken. Results obtained at Conway, where culture conditions were good, showed close agreement between haemacytometer counts and the dilution method. The remaining results presented here were obtained under poor culture conditions, and the figures obtained from them are probably far too low.

Method.

The culture medium used was sea-water Erdschreiber (see Gross, 1937). The following dilution method is based on that used in the bacteriological examination of water supplies (Ministry of Health, 1940).

For a nanoplankton of from 1 to 10 organisms per mm^3. (the density most frequently encountered) a preliminary dilution of $^1/_{100}$ was made, by adding 1 ml. of the sea-water sample to 99 ml. of sterile sea water in a sterile, stoppered bottle, and shaking by inverting twenty-five times. Fifteen test-tubes, plugged, sterilized, and each containing 9 ml. of sterile Erdschreiber, had previously been prepared and arranged in

three batches of five. With a sterile pipette 1 ml. of the preliminary dilution was added to each test-tube of the first batch. Then, with a fresh pipette, the contents were mixed by sucking up and down ten times and 1 ml. was transferred to a tube of the second batch. This process was repeated for the remaining four tubes in each of the first and second batches, using the same pipette. Then with a fresh pipette and following the same procedure, 1 ml. was transferred from each test-tube of the second batch to a tube of the third batch.

The three batches of test-tubes then contained, respectively, dilutions of $^1/_{1,000}$, $^1/_{10,000}$, and $^1/_{100,000}$, i.e., approximately 10 mm^3., 1 mm^3., and 0·1 mm^3. of the original sea water. They were placed in windows facing north. Exposure to direct sunlight, even for short periods when the sun was low, or for a few minutes only when the sun was high, often proved fatal to small flagellates. A series of test-tubes hung in a south window, where they were never exposed to direct sunshine, did not develop such a variety of organisms as a similar series in a north window. Apparently the wide temperature variations in south windows are unfavourable to many forms. It was found that cultures usually developed in some of the test-tubes after 1 to 2 months in summer and 2 to 4 months in winter.

The preliminary dilution was varied to $^1/_{1,000}$ when the nanoplankton was abundant and culture conditions good, and to $^1/_{10}$ when the nanoplankton and culture conditions were poor.

The original bacteriological method is used for estimating numbers of sewage bacteria in water samples. A count of the number of test-tubes developing cultures in each of the three batches indicates the probable number of organisms in the original sample. This is shown in statistical tables in the Ministry of Health's publication (1940). Standard errors are given by S w a r o o p (1938). These are rarely less than half the probable numbers.

Subculturing must be carried out about every month if nanoplankton organisms have to be kept for identification. Changes often take place in cultures. Those which have been maintained for a long time generally grow more rapidly and become more dense than when first isolated. In mixed cultures there may be a succession of forms, some dying out and being replaced by others. Morphological changes may make specific identification more difficult. In old cultures *Platymonas apiculata* Butcher developed many granules in its chloroplast, which was smooth in first-isolated individuals. This species and *Pavlova gyrans* Butcher persisted as non-motile strains for long periods, especially in strong light. There sometimes appeared to be a decrease in size. *Cryptomonas acuta* Butcher measured 10—15μ in the later cultures from which the species was described, whereas cells of presumably the same species measured 15—20 μ in early cultures. This parallels the well known size-variability of diatoms, which occurs both in culture and under natural conditions.

An attempt was made to isolate cultures on plates of solid medium (Erdschreiber with 2 % agar). No growth of motile flagellates was

obtained, but some species of *Nitzschia* and an encysted strain of *Platymonas apiculata* grew satisfactorily.

A systematic survey of the organisms observed.

There is little information available about the relative importance of the various groups represented in the nanoplankton. Without a culture method, identification is so difficult that it might be supposed that reproductive cells of algae make a substantial contribution to the flagellate population. A list of the species obtained in culture may therefore be interesting, for probably only the most abundant organisms will have been observed in the limited time which could be spared for this work. It appears that swarmers of sessile algae were relatively very sparse and that the vast majority of flagellates are permanent members of the nanoplankton. The most generally abundant organism in British coastal waters and the North Sea seems to be the 1·5 μ chrysomonad *Chromulina pusilla* Butcher. It is most remarkable that this should previously have been undescribed. The frequent abundance of Cryptomonadineae is also remarkable in view of the previous evidence that this group is scantily represented in the sea (see Fritsch, 1935).

Unfortunately, little attention was paid to the identification of diatoms.

The main groups, in order of frequency and abundance, were:— Chrysomonadineae, diatoms, Cryptomonadineae, Chlorellaceae, and Chlamydomonadineae. Bacteria were always very abundant. Peridineae, Myxophyceae, Euglenineae, occasional yeasts, *Stichococcus*, and various sessile and colonial algae appeared rather infrequently.

The numbers per ml. given, with their standard errors, in the list which follows refer to the probable densities of the forms concerned in the water samples from which they originated, estimated, unless otherwise indicated, by the dilution method. The other methods used are indicated by the following signs:— CHC — concentration of sample by membrane-filtering followed by haemacytometer counts; UHC — similar counts of unconcentrated samples.

For all the specific identifications I am indebted to Dr. R. W. Butcher.

CHLOROPHYCEAE.

Volvocales.

CHLAMYDOMONADINEAE.

Chlamydomonadaceae.

Platymonas apiculata Butcher (1951) (10μ). Conway tanks 8/46, swarming 80,000/ml. UHC at surface, and up to 1,500/ml. CHC at mid-depths; swarming at surface seen with unaided eye; plate counts from solid medium indicated 200/ml. Helford River, Cornwall, 10/46, 130 ± 70/ml. Thick culture appeared fortuitously in aquarium containing dead mussels at Fisheries Laboratory, Lowestoft, 2/47. R. Crouch, Essex, often about 1,000/ml. CHC.

Polyblepharidaceae.

Pyramimonas grossi Parke (1949) (7μ). Isolated at Plymouth by Dr. Gross. R. Crouch 7/48, 20 ± 20/ml.; 12/48, 80 ± 50/ml.

TETRASPORINEAE.

Coccomyxa littoralis (Wille) (5μ). Isolated from Conway tanks in 1934 (Cole, 1936) but not observed during the present investigations.

CHLORODENDRINEAE.

Prasinocladus lubricus Kuck. R. Crouch opposite Fambridge (fully saline conditions), swarmers 20 ± 20/ml.

Chlorococcales.

Chlorellaceae.

Chlorella stigmatophora Butcher (5μ). Isolated at Port Erin, Isle of Man, by Dr. Parke. R. Crouch 1/48, 20 ± 20/ml.

C. salina Butcher (6μ). Conway tanks 9/46, 200 ± 200/ml.

C. ovalis Butcher (5—10μ). Conway estuary 4/47, 20 ± 20/ml. R. Crouch 8/47, apparently over 5,000/ml. Oval non-motile forms resembling this species were seen frequently in water samples from Essex creeks and from the North Sea far from land.

Nannochloris maculatus Butcher (2—3μ). Essex creeks.

N. atomus Butcher (2—3μ). R. Crouch 8/47, about 5,000/ml. Minute cells practically indistinguishable from this and the preceding species were often abundant in haemacytometer counts of Essex samples and appeared frequently in dilutions.

Ulotrichales.

Ulotrichaceae.

Ulothrix subflacca Wille. Conway tanks 4/47, swarmers? 20 ± 20/ml.

Stichococcus marinus Butcher (3—4μ). Essex creeks.

Chaetophorales.

Chaetophoraceae.

Ulvella lens (Crouan). Essex creeks; swarmers? 20 ± 20/ml. in R. Crouch 9/48.

CHRYSOPHYCEAE.

Chrysomonadales.

CHRYSOMONADINEAE.

The majority of flagellates observed belonged to this group. The minute form referred to below was generally the most abundant, but larger, spherical species of *Chromulina* Cienk and *Dicrateria* Parke, varying in size from 3 to 10μ, also occurred commonly in cultures and were observed in counts from all sources, often several thousand/ml. CHC.

Chromulinaceae.

Chromulina pusilla Butcher (1·5μ). Particularly abundant, widely distributed and hardy in culture. Flagellates less than 2μ in size,

probably of this species, were seen frequently in haemacytometer counts from all sources except the Arctic. Cultures obtained from Conway, Cornwall, Essex, and the North Sea all proved to be this species. It appeared in most series of dilutions, often as the dominant form. Probable densities observed include the following (number per ml.): F tank Conway 8/46, 2,300 ± 1,100: Conway estuary 9/46, 3,480 ± 1,890: R. Crouch 8/47, 140 ± 70: Firth of Forth, 12/49, 540 ± 330.

No other flagellate species less than 2μ in size was observed.

Isochrysidaceae.

Dicrateria inornata Parke (5μ). Isolated Plymouth 11/35 by Dr. Gross. Conway tanks 8/46.

Prymnesiaceae.

Prymnesium sp. (5μ). Conway tanks 4/47, 20 ± 20/ml.

Ochromonadaceae.

Pavlova gyrans Butcher. Helford River, Cornwall, 10/46.

Chrysocapsaceae.

A species of *Phaeocystis* was isolated from the North Sea 1/49 (swarmers?) 2 ± 2/ml.

BACILLARIOPHYCEAE.

Centrales.

Species of *Coscinodiscus, Melosira,* and *Skeletonema* were obtained in culture, together with several other forms which were undoubtedly centric diatoms, indicating densities of up to about 50/ml. Other brown, non-motile organisms, which were often several hundred/ml., may belong to this group. Their cells were 2—4×2—12μ, forming short chains which stuck to the bottom and sides of the culture tubes.

Pennales.

BIRAPHIDEAE.

Navicula halophila (Grun.) Cleve (10μ). River Roach, Essex, 7/47, 700 ± 410/ml.

Nitzschia ovalis Arnott (10μ). Conway tanks 8/46.

N. longissima (Ehr.) (80μ). Conway tanks 8/46.

N. closterium (Ehr.) (35μ). Conway tanks 8/46, 200 ± 200/ml. R. Roach, 7/47, 40 ± 30/ml. Observed frequently in haemacytometer counts from all sources, sometimes at densities of several thousand per ml. The triradiate form appeared in dilutions from a brackish pond near Burnham, Essex.

CRYPTOPHYCEAE.

Cryptomonadales.

CRYPTOMONADINEAE.

Cryptomonas acuta Butcher (15μ). Conway tanks 9/46, 20 ± 20/ml. R. Crouch 6/48, 80 ± 50/ml.

Cryptochrysis fulva Butcher (7μ). Conway tanks 8/46.

C. lateralis Butcher (7μ). Conway tanks 8/46, 1,300 ± 700/ml.

C. virescens Butcher (7μ). R. Crouch.

Hemiselmis rufescens Parke (8μ). Isolated from off Port Erin by Dr. Parke. Conway estuary 9/46, 20 ± 20/ml.

Hillea marina Butcher (2μ). Conway tanks 8/46, 3,300 ± 1,700/ml.

DINOPHYCEAE.

Dinokontae.

PERIDINIEAE.

Gymnodiniaceae.

Massartia rotundata (Lohmann) Schiller (15μ). Conway tanks 9/46, 20 ± 20/ml. This was originally described as a species of *Amphidinium*. Lebour (1925) termed it *Gymnodinium minutum nom. nov.*

EUGLENINEAE.

Euglena sp. This form, 50μ long, was common in the R. Crouch, especially in the upper reaches near Fambridge, 8 and 9/48, up to 100/ml. CHC. It swam freely but when it came in contact with a surface it crawled about upon it by the movement of very large peristaltic bulges.

MYXOPHYCEAE.

Chroococcales.

Chroococcaceae.

1μ specks virtually indistinguishable from the two minute species which follow are often numerous in haemacytometer counts, giving the impression that blue-green algae are abundant. The fact that these exceptionally hardy forms each appeared in culture once only rather contradicts that impression. The possibility remains that other more abundant species or strains do not develop readily in cultures.

Synechococcus elongatus Näg. (1μ). Conway tanks 8/46.

Synechococcus bacillaris Butcher (1μ). Conway tanks.

Stigonematales.

A filamentous form, probably *Mastigocoleus* or *Mastigocladus*, was isolated from Conway tanks 9/46.

FUNGI.

Yeasts and, less frequently, moulds sometimes appeared in old cultures. Yeast cells measuring about 5μ, oval and often lemon-shaped because of terminal protuberances, were seen in the R. Crouch, up to 1,000/ml. CHC.

Results from various sources.

The first trials of the method were carried out at the Conway tanks (Table 1). The nanoplankton was estimated by concentration and haemacytometer counts (column CHC) at about the time the dilutions were made. The types and sizes of organisms counted were recorded, so that it was possible, when the cultures developed, to compare the

densities obtained by each method. The agreement turned out to be fairly close, good culture conditions being available in a cool, ground-floor room. The more dilute batches of tubes from these series were soon discarded but the 1 mm^3. batches were kept. By 16/4/47 four of the five tubes from B tank had developed cultures of the minute blue-green alga *Synechococcus elongatus* Näg., whilst the organisms seen earlier had disappeared. Evidently the time for which cultures are kept before examination is important. To obtain maximum numbers of different organisms by the dilution method it will be necessary to keep the cultures for at least six months and to examine them every month, or perhaps even more frequently.

Table 1.

	1 $mm.^3$	0.1 $mm.^3$	0.01 $mm.^3$	Probable number/ ml.	Standard error	Number/ml. CHC.
A Tank, Conway. Dilutions made 11/8/46; counts made 12/8; cultures examined 11/9.						
Hillea marina	5	1	0	3,300	1,700	2,500
Chromulina pusilla	1	0	0	200	200	Not noted
Dicrateria sp. (5μ)	0	1	0	200	200	250
Incertae sedis (5μ)	2	0	0	500	300	250
Nitzschia closterium	0	1	0	200	200	Not seen in 0·4 $mm.^3$
Total organisms	5	2	0	4,900	2,800	2,750
B Tank, Conway. Dilutions made 11/8/46; counts made 12/8; cultures examined 12/9.						
Cryptochrysis lateralis	4	0	0	1,300	700	2,750
Colourless 4μ flagellate	1	0	0	200	200	Not noted
Total organisms	4	0	0	1,300	700	2,750
F Tank, Conway. Dilutions made 11/8/46; counts made 12/8; cultures examined 14/9.						
Chromulina sp. (4μ)	5	1	0	3,300	1,700	2,250
C. pusilla	5	0	0	2,300	1,100	4,250
Colourless 4μ flagellate	1	0	0	200	200	250
Total organisms	5	1	0	3,300	1,700	6,500

Two replicate series of dilutions were taken from one sample and examined twice after prolonged intervals (Table 2). Brown, non-motile forms were frequent, particularly at the second examination. It appeared that they were excluded at first by faster-growing flagellates, but were able to withstand better than the flagellates crowded conditions in old cultures. They formed short chains and were probably centric diatoms. Although only two tubes of the 10 mm^3. batch in the second series developed these forms, it is considered from their distribution in the other batches that they had been present initially in all five tubes, but

were excluded by flagellates. The figure 5 is therefore placed in brackets in Table 2 and in similar instances in Table 3 and 7.

The probable numbers deduced from the two series agreed with one another closely, but the records from haemacytometer counts gave greater numbers of the larger flagellates and no non-motile forms. A fifth part of each of five haemacytometer fields was examined during the counts. This should have detected organisms present at densities of over 500 per ml., so probably the non-motile forms were either wrongly identified as immobilized flagellates, or present as swarmers.

Table 2.

Conway Estuary at H.W. Water pumped into A tank 12/9/46; counts and two replicate series of dilutions made 15/9. Cultures examined 24/12 and again on 19/4/47.

	10 mm.^{3}	1 mm.^{3}	0.1 mm.^{3}	Probable number/ml.	Standard error	Number/ml. CHC
1st series:—						
Chromulina pusilla	5	5	1	3,480	1,890	2,800
Dicrateria sp. (10μ)	1	0	0	20	20	
Cryptomonas acuta	1	0	0	20	20	600
Hemiselmis rufescens	1	0	0	20	20	
Other flagellates (2—5μ)	3	0	0	80	50	
Brown non-motile forms (2—5×5—10μ)	5	4	0	1,300	670	
2nd series:—						
Chromulina pusilla	5	5	1	3,480	1,890	
Cryptomonas acuta	1	0	0	20	20	
Massartia rotundata	1	0	0	20	20	
Other flagellates (2—5μ)	4	0	0	130	70	
Brown non-motile forms	(5)2	3	0	(790)	(450)	
Stigonematales	0	1	0	20	20	
Total organisms (each series)	5	5	1	3,480	1,890	3,400

Examples of other series made at Conway are given in Table 3. The numbers and types of organisms varied greatly, but flagellates were dominant in all series except those made in April 1947, when diatoms were more abundant. Estimates of density obtained at Conway varied between 200 and 5,000/ml. Allen (1919) found from 464 to perhaps 1,000/ml. off Plymouth in September, with diatoms dominant. In enriched waters much higher densities may appear. In Kyle Scotnish 200,000 to 1,500,000/ml. were recorded, with still higher densities in the shallow and enclosed Loch Craiglin (Gross, Raymont, Nutman, and Gauld, 1946). Though difficulty was reported in distinguishing the smallest flagellates from bacteria, these figures do not seem excessive for greatly enriched waters. Similar populations appear occasionally in Essex oyster-pits during the summer. One pit near Paglesham, which had been isolated for about a week during neap tides, was found on 14/7/48 to contain Chlorellaceae (5μ) 3,250,000/ml.,

flagellates 150,000/ml., abundant *Nitzschia*, and a very rich zooplankton, including all naupliar stages of the barnacle *Elminius modestus*. The water was turbid and the pH 8·5 at about mid-day. The source of enrichment was probably the mud-bottom and a few dead oysters. Densities of laboratory cultures are often of this order but may be much greater, particularly in cultures of the smallest organisms, e.g., *Synechococcus*.

Table 3.

Helford River, Cornwall. Collected and dispatched 2/10/46. Dilutions made at Conway 3/10; cultures examined 13/11 and 14/1/47.

	10 $mm.^3$	1 $mm.^3$	0.1 $mm.^3$	Probable number/ml.	Standard error
Chromulina pusilla	(5)	5	1	3,480	1,890
Chrysomonadineae (5μ)	2	1	0	70	40
Cryptomonadineae (5μ)	1	2	1	80	50
Platymonas apiculata	4	0	0	130	70
Other flagellates (2—7μ)	1	1	0	40	30
Nitzschia closterium	3	0	0	80	50
Brown non-motile forms	5	1	0	330	170
Total organisms	5	5	2	5,420	3,300
Conway estuary at H.W. Dilutions made 17/4/47. Cultures examined 26/6.					
Chromulina pusilla	2	0	0	50	30
Prymnesium sp. (5μ)	1	0	0	20	20
Other flagellates (5μ)	0	1	0	20	20
Brown non-motile forms (4—5×4—20μ)	3	2	0	140	70
Chlorella ovalis	0	1	0	20	20
Total organisms	4	2	0	220	110
Conway, F. Tank, as above.					
Chromulina pusilla	2	1	0	70	40
Other flagellates (3μ)	1	0	0	20	20
Nitzschia sp. (50μ)	4	1	0	170	80
Chlorella sp. (5μ)	3	1	0	110	60
Ulothrix subflacca	0	1	0	20	20
Total organisms	5	3	0	790	450

Investigations were begun at Burnham-on-Crouch, one of the centres of the Essex oyster industry, in the summer of 1947. The only window available was one facing south. Cultures were hung at the top of this, so high that they were never reached by direct sunlight. Several series of dilutions were made, but the majority were not examined thoroughly as it was obvious that they were not developing satisfactorily, probably because the light was too bright or the temperature too variable. The

Table 4.

River Roach, Essex, about 1 mile above Paglesham, 1 hour before low water. Dilutions made 13/7/47, cultures hung in south window and examined on 5/8 and 13/10.

	10 mm.^{3}	1 mm.^{3}	0.1 mm.^{3}	Probable number/ ml.	Standard error.	Number/ ml. CHC.
Navicula halophila	5	1	0	330	170	500
Biraphideae (45μ)	0	1	0	20	20	—
Flagellates (2—10μ)	0	0	0	—	—	9,500
1μ specks	—	—	—	—	—	40,000
River Roach, confluence with R. Crouch, half-ebb, as above.						
Navicula halophila	5	2	1	700	410	1,500
Nitzschia closterium	1	1	0	40	30	—
Other diatoms	1	0	0	20	20	—
Chlorellaceae (2μ)	1	0	0	20	20	—
Flagellates (2—10μ)	0	0	0	—	—	1,000
1μ specks	—	—	—	—	—	102,000

only organisms observed to develop were diatoms and an occasional *Chlorella*, though flagellates had been abundant in the water from which the dilutions were made. Two examples of these series are given in Table 4. The good agreement between densities of *Navicula halophila* indicated by dilutions and the counting method shows that this species can thrive under widely fluctuating conditions.

Better quarters became available later, where there was a skylight always shaded by a tree. Two exactly similar series of dilutions were

Table 5.

River Crouch, Essex, opposite Burnham. Dilutions made 30/8/47; cultures examined 10/12/47 and 2/48.

	10 mm.^{3}	1 mm.^{3}	0.1 mm.^{3}	Probable number/ ml.	Standard error.
A. Hung in south window.					
10/12/47.					
Brown non-motile forms	4	0	0	130	70
2/48					
Brown non-motile forms	5	1	0	330	170
Chromulina pusilla	3	2	0	140	70
Chlorella ovalis	3	3	1	210	100
B. Hung in shaded skylight					
10/12/47					
Brown non-motile forms	1	0	0	20	20
Chromulina pusilla	4	0	0	130	70
Chlorella ovalis	5	5	5	>5,000	
2/48. Not much changed from 10/12/47.					

made and one was hung in the skylight, the other high up in a south window. The two series were examined after four months, including a long period of hot, dry summer and autumn weather. That in the shaded skylight had developed cultures of *Chlorella* in every tube, with some admixture of *Nannochloris* sp., *Chromulina pusilla*, and a brown non-motile form. That in the south window had developed brown non-motile forms in most of the 10 ml. tubes, but no *Chlorella*. Apparently conditions in the south window did not allow the multiplication of *Chlorella*, whilst in the shaded window *Chlorella* thrived so as to exclude diatoms.

The two series were re-examined after a further two months of cold, dull, winter weather. By then *Chlorella* and *Chromulina pusilla* had appeared in most of the tubes in the south window, showing that these forms had survived the earlier unfavourable period. Evidently excessive variations of light and temperature may cause dilution methods of estimation to give very variable results (Table 5).

Table 6.

River Crouch, Essex. Dilutions made 20/6/48; cultures examined 19/9/48.

	10 $mm.^3$	1 $mm.^3$	0.1 $mm.^3$	Probable number/ ml.	Standard error.
Chromulina pusilla	3	1	0	110	60
Cryptomonas acuta	3	0	0	80	50
Pyramimonas grossi	1	0	0	20	20
Other flagellates (2—15μ)	4	1	0	170	80
Nitzschia sp. (80μ)	1	0	0	20	20
Other Biraphideae (12μ)	2	0	0	50	30
All organisms	5	2	0	490	280

River Crouch. Dilutions made December 1948; cultures examined 15/3/49.

Chromulina pusilla	2	0	0	50	30
Cryptomonadineae	4	2	0	220	110
Pyramimonas grossi	3	0	0	80	50
Other flagellates	2	0	0	50	30
Brown non-motile forms	1	0	0	20	20
Chlorella ovalis	1	0	0	20	20
All organisms	5	2	0	490	280

Another change of quarters provided a north window. The building was a single-storey hut and so was subject to rather large temperature variations, but an interesting range of organisms appeared in the series shown in Table 6.

Routine voyages from the Fisheries Laboratory, Lowestoft, afforded opportunities of surface sampling far from land. As it was winter and culture conditions were poor, the inoculations used were ten times as concentrated as usual (Table 7). Counts in the "Ernest Holt" showed nanoplankton densities too low to be estimated accurately by the

Table 7.

Southern Bight of North Sea. Collected far from land by Mr. Michael Mistakidis from the "Sir Lancelot" 10/1/49. Dilutions made at Burnham 14/1; cultures examined 23/2.

	100 mm.^{3}	10 mm.^{3}	1 mm.^{3}	Probable number/ ml.	Standard error.
Chromulina pusilla	(5)1	2	0	(49)	(28)
Chrysomonadineae (5μ)	4	1	0	17	8
Crysocapsaceae	1	0	0	2	2
Biraphideae	1	0	0	2	2
Brown non-motile forms	2	2	0	9	5
All organisms	5	3	0	79	45

North Sea, near Flamborough Head, about 5 miles from land, 54°02′N., 00°00′E., 15/11/49. Collected from the "Ernest Holt" with Lumby Surface Sampler. Samples examined and dilutions made without delay. Tubes kept on board in artificial light and brought back to Burnham-on-Crouch 6/12. Cultures examined May 1950.

	100 mm.^{3}	10 mm.^{3}	1 mm.^{3}	Probable number/ ml.	Standard error
Chromulina pusilla	1	0	0	2	2
Biraphideae	2	0	0	5	3
Brown non-motile forms	(5)	4	0	130	67
All organisms	5	4	0	130	67

Atlantic Ocean, within Arctic Circle, 69°N., 08°E., 19/11/49.

Yellowish-green non-motile forms (2—4μ)	3	1	0	11	6

North Sea, opposite Firth of Forth, 56°17′N., 01°30′W., 5/12/49.

Chromulina pusilla	(5)	5	2	542	330
Chrysomonad (5μ)	2	0	0	5	3
Biraphideae	1	1	0	4	3
Coscinodiscus (20×20—40μ)	1	0	0	2	2
Other Centrales	1	0	0	2	2
Brown non-motiles *indet.*	2	1	0	7	4
All organisms	5	5	2	542	330

haemacytometer method, without increasing the preliminary concentration through the membrane-filter to perhaps 200 times. Such an increase would make the process of filtering very tedious. The densities seemed, nevertheless, much greater than those indicated by the culture method. Oval non-motile green 2—5μ cells, which were seen frequently in the fresh samples, did not appear in the cultures. This is hardly surprising. On the contrary it is remarkable that so many species from

the open sea thrived under such unsatisfactory conditions. If a thermostatically-controlled culture-cabinet were used, quantitative culturing would appear to be a very practicable method of nanoplankton estimation. It is likely to be particularly useful at sea, where concentrated work at the time of sampling is often difficult, and in researches on growth of oyster larvae, where it is important to distinguish with certainty between indigestible non-motile forms and easily digestible flagellates.

Summary.

Nanoplankton organisms are probably very important in marine ecology, but little is known of their systematics, whilst estimation of the abundance of the smallest and most numerous is difficult.

Quantitative dilutions of sea-water samples were carried out, followed by the bacteriological method of serial dilution into three successive batches of five test-tubes, which then contained the equivalent of 10, 1, and 0·1 mm^3. of the original sample, inoculated into Erdschreiber.

The organisms obtained in culture are listed, with notes on their occurrence. The 1·5μ flagellate *Chromulina pusilla* was the most generally abundant. Apart from bacteria, the main groups, in order of abundance, were Chrysomonadineae, diatoms, Cryptomonadineae, Chlorellaceae, and Chlamydomonadineae. Occasionally Peridineae, Myxophyceae, Euglenineae, yeasts, *Stichococcus,* and various sessile and colonial algae were encountered.

When culture conditions were good, estimates of abundance of dominant organisms in estuaries, creeks, and the open sea usually varied between 500 and 5,000 per ml., which agreed fairly well with estimates obtained by membrane filtering.

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Fishing Capacities of Lowestoft and Aberdeen Trawls when Used on Flatfish Grounds.

By

B. B. Parrish.

Introduction.

As a result of the comparative trawling experiments which have been conducted since the war, a great deal has been learned regarding the relative efficiencies of different trawl gears used by European countries in different fisheries in the North Sea. These experiments have shown that not only do trawls of different dimensions and design differ in their absolute catching capacities, but that their relative efficiencies are not the same for all species of fish. M a r g e t t s (1949) describes a series of experiments in which the gears used by the research vessels "Sir Lancelot" and "Platessa" were tested against the gears used by other countries, and P a r r i s h (1949) deals in some detail with the results obtained from one of these experiments carried out between the research vessels "Sir Lancelot" and "Explorer". This experiment was conducted on a predominantly roundfish ground in Scottish waters, in which the "Sir Lancelot" used the customary southern North Sea trawl with large square and wooden bosom bobbins, and the "Explorer" the lighter roundfish gear used by Scottish vessels. The results of this experiment showed that the gears used by the two vessels possessed markedly different catching capacities for different species of fish: the "Explorer" outfished the "Sir Lancelot" for roundfish, whereas, the "Sir Lancelot" caught greater quantities of the bottom-living forms such as flatfish, anglers, skates and rays.

In view of these results, and in order to determine the difference between the catching capacities of these two gears on a predominantly flatfish population, it was decided to conduct a similar test between the two vessels on a southern North Sea ground. Also, in view of the widespread use of "tickler-chains" by commercial vessels in these waters, it was decided to incorporate in this experiment a test of the effect of a tickler chain on the catching capacities of the two nets.

The present experiment was the result of continued co-operation between the Fisheries Research staffs of the Ministry of Agriculture and Fisheries and the Scottish Home Department. Further inferences from the data may appear in later papers produced by collaborators in either Department. The hauls were carried out on a ground of 15 fathoms depth approximately 30 miles north-east from the "Smith's Knoll" lightship in August 1949.

Experimental Design.

Experience has shown that the numbers of each species of fish caught in replicate hauls on the same grounds by a trawl-net may vary between wide limits. This variability my be caused by a number of independent factors such as local movements of the fish shoals over the experimental period, diurnal variations in the availability of different species to capture, slight changes in the grounds fished from haul to haul and small changes in the behaviour of the trawl in successive hauls. It is necessary, therefore, when assessing the relative catching capacities of two gears from the results of a series of replicate hauls, to take into consideration the variability in the numbers of fish caught due to such uncontrollable factors as are mentioned above. It has been customary in past experiments to assess the relative efficiencies of different trawl gears from the differences between their gross catches in equivalent fishing times. While this may be the only practicable means in some cases, viz., when commercial vessels' catches are compared, and may be desirable when only a knowledge of the total quantities of fish which different vessels and gears can catch under normal operational conditions is required, it may result in erroneous conclusions being drawn regarding the relative efficiencies of different gears, due to the effect of the random fluctuations discussed, particularly when the differences between the total catches are small, and when the number of replicate hauls is limited.

An alternative method of analysis, and the one adopted for this experiment, is by means of the statistical "analysis of variance", as used in the analysis of agricultural field experiments. In this method account is taken of the variation of the catches between successive hauls, and this is sub-divided into that due to the differences between the different gears, that due to such systematic factors as time, and that due to the random uncontrollable factors such as changes in shoal density, etc. The variability due to the difference between the gears can then be tested for significance against that due to the random factors.

In order that statistical methods may be used in the analysis of the results, it is important that the experiment should be designed so as to eliminate any bias caused by such factors as fishing with one of the gears always at more favourable times than with the other. This is particularly important when species which show marked diurnal variations in availability to capture are being fished. In this experiment, fishing was carried out on each of six days, each day's trawling being conducted on the same ground marked by a dahn, but with slight

changes in the ground fished being made from day to day (this corresponds to the "blocks" in a randomized block field experiment). On each day six two-hour hauls were made at fixed times by each vessel, three with and three without the use of a "tickler-chain". The hauls with and without a tickler-chain were made in pairs by each ship, but the order in which the pairs of hauls were made was randomized over the trawling times (corresponding to the randomization of treatments within "blocks") so that, over the whole experimental period, hauls with and without a tickler-chain were made at each sampling time. At each trawling time, the "Explorer" and "Sir Lancelot" shot and hauled their gears simultaneously and trawled on parallel courses as close together as possible. The engine revolutions and length of warp used were those normally adopted by each vessel and no change in either was made during the course of the experiment.

Description of the Trawls used.

The trawls used by the two vessels during the experiment and the dimensions of the main components of the nets were as follows:—

Length of	"Sir Lancelot"	"Explorer"
Headline	80 ft.	100 ft.
Groundrope	48 ft.	46 ft.
Bosom	20 ft.	20 ft.
Top wings	32 ft. 6-inch mesh	39 ft. 5½-inch mesh
Lower wings	66 ft. 5- „ „	54 ft. 5½- „ „
Square	30 ft. 6- „ „	11 ft. 5½- „ „
Belly	28 ft. 5½—4½-inch mesh	23 ft. 5½—3½-inch mesh
Baitings	28 ft. 5½—4½- „ „	23 ft. 5½—3½- „ „
Cod-end	21 ft. 80 mm.[1])	22 ft. 80 mm.[1])
V. D. Gear	30 fm. 2½″ bridles	30 fm. 2½″ bridles
Tickler-chain	½″ chain between dan-lenos	½″ chain between dan-lenos
Headline floats	24; 6 on each wing, 11 on centre.	48; 11 on each wing, 20 on centre.

[1]) Differences in cod-end mesh size were experienced during the experiment. These are discussed later.

The two nets also possessed important differences in the make-up of the groundropes and bosom. The "Explorer's" was equipped with light groundropes, consisting of 2½-inch wire bound with 2½-inch manilla rope, and it had a soft bosom without bobbins, whereas the "Sir Lancelot's" groundropes were bound in addition with $^3/_8$-inch chain, and the bosom was equipped with 12-inch wooden bobbins.

From this description it will be seen that the "Sir Lancelot's" net was of greater overall length than the "Explorer's", had a much larger, slacker square, and possessed heavier groundropes and bosom. The "Explorer's", on the other hand, possessed a longer headline and top wings. The dimensions given here for the "Explorer's" net differ from

those used in the earlier experiment between the two vessels, particularly in the lengths of the headlines and groundropes (Margetts 1949; Parrish 1949), but the results of a trawling test carried out on the "Explorer" using the two trawls showed that there was no significant differences between their catching capacities. The net used by the "Explorer" in this experiment was more characteristic of the type in current use by Scottish trawlers fishing in northern North Sea waters.

Results.

The results of the experiment, expressed as the numbers of fish of each species in each haul by the two vessels, are given in Table I.

A glance at these results shows that the population sampled was composed principally of plaice and dabs. Gurnards were also caught in fair quantities and whiting appeared consistently in the "Explorer's" catches. Other species appeared in the catches in small numbers or only sporadically and for the purpose of comparison have been grouped as "Miscellaneous"; species represented under this heading included, sole, turbot, cod, horse mackerel (*Caranx trachurus*), John Dory (*Zeus faber*), and red mullet (*Mullus surmuletus*). It will be seen also that seven hauls, six by the "Sir Lancelot" and one by the "Explorer", failed to give comparable data due to damage to the gear. As appears later, estimates of these missing observations have been made from the remaining data and have been used in the comparison between the two vessels' catches, thus yielding a total of 72 hauls from which the differences in the catching capacities of the two vessels' gears can be determined.

The estimate of the difference between the catches of the gears has been tested for significance against the uncontrolled variability in the number of fish caught from haul to haul. For this technique to be valid, however, it is necessary that the data should be approximately "normal", and that the variance should be the same for all groups. Table I shows that the numbers of fish of each species caught by each item of gear over the 18 replications varied between wide limits, the extent of this variation being greater, the greater the number of fish caught. It is possible, however, to correct for this difference between the sets of data by using transformed values in the analysis. In this experiment, the logarithms of the catches of each species have been used and, in order to overcome the difficulty when no fish were caught in any haul, the transformation has been to log $(N+1)$. The transformed values of the catches are tabulated in Table II.

Also included in Table II are the estimates for the missing hauls. These values have been determined from the remaining data by a statistical method which reduces the "error" variability to a minimum, and is described in the Appendix. The estimated values are used in the analysis of variance as observed items, but for each estimated value one "degree of freedom" is lost from the estimation of the "error" component of variability.

The analysis of the transformed values has been conducted for each

species separately, and in each case the total variability, calculated for the 72 hauls, has been sub-divided into that due to the differences between the catches of the two nets, that due to the differences between the daily totals, that due to a time effect, and that due to the random uncontrollable causes of variation, called "error". For full details of this method of analysis, readers are referred to R. A. Fisher (1946) and G. W. Snedecor (1946) but the stages in the calculation of the respective estimates of variance are given in the Appendix.

In the analysis, it will be seen that of the total number of degrees of freedom, three are allotted to the comparison between nets, and the estimate of variance derived from them can be tested against the error component to determine whether there is a significant difference between the catches of the four items of gear. It is possible, however, to sub-divide the three degrees of freedom further into single comparisons between pairs of the gear items, so that more specific knowledge of the catching capacities of the four gear components can be obtained.

The three most instructive comparisons in this experiment, and the

Table I. Numbers of Fish

			Day 1			Day 2			Day 3		
Plaice	E.	a	115	193	213	162	85	201	223	155	139
		b	0	2	14	5	x	6	12	3	8
	S.L.	a	297	x	201	170	192	124	237	x	263
		b	41	43	x	99	34	70	52	79	101
Dabs	E.	a	123	221	301	211	99	118	253	207	119
		b	4	7	12	10	x	20	30	17	7
	S.L.	a	588	x	299	559	510	546	462	x	476
		b	176	154	x	268	123	257	82	277	229
Gurnards	E.	a	62	36	20	49	42	34	34	37	41
		b	3	7	12	12	x	2	7	4	7
	S.L.	a	16	x	19	35	39	26	24	x	27
		b	15	29	x	34	8	18	4	19	15
Whiting	E.	a	8	5	1	7	0	2	0	0	6
		b	15	13	6	16	x	8	7	5	20
	S.L.	a	0	x	1	0	5	0	1	x	1
		b	2	1	x	0	0	4	2	5	5
Miscellaneous	E.	a	16	2	12	2	6	30	4	2	4
		b	6	0	3	1	x	1	3	4	1
	S.L.	a	9	x	29	17	4	6	18	13	x
		b	7	14	x	11	6	25	3	8	17
All Species	E.	a	324	457	547	431	232	385	514	401	309
		b	28	29	47	44	x	37	59	33	43
	S.L.	a	892	x	349	781	750	702	739	x	773
		b	241	241	x	372	171	374	143	388	367

E. = "Explorer" S.L. = "Sir Lancelot" a = with tickler b = without tickler

ones for which the single degrees of freedom have been utilized are as follows:—

(1) Between "Sir Lancelot's" catches and "Explorer's" catches.
(2) Between the with-tickler-chain hauls and those without a tickler-chain.
(3) The interaction between (1) and (2), which measures whether the tickler-chain has had the same effect on the catches of the two vessels.

The three estimates of variance for these three independent comparisons can then be tested for significance against the error variance.

The completed analysis of variance, giving the numbers of degrees of freedom, the sums of squares, and the mean squares for each species of fish are given in Table III. Also included are the results of the significance tests carried out on the three main net comparisons. Three notations have been used, representing different levels of significance; XX, which shows significance at the 1 % probability level; X, which

caught in each Haul.

			Day 4			Day 5			Day 6		
Plaice	E.	a	130	203	123	187	324	79	76	250	229
		b	2	2	6	7	10	23	11	7	14
	S.L.	a	115	215	x	248	301	224	112	202	151
		b	x	37	x	50	92	91	52	58	57
Dabs	E.	a	120	242	105	204	195	141	124	121	129
		b	8	1	15	25	11	58	19	22	40
	S.L.	a	230	484	x	641	748	676	339	563	275
		b	x	80	x	199	196	352	170	210	369
Gurnard	E.	a	87	52	56	56	44	22	60	53	41
		b	11	5	13	7	11	5	17	9	21
	S.L.	a	21	49	x	36	72	40	59	11	22
		b	x	11	x	4	6	18	12	14	16
Whitings	E.	a	31	10	7	2	3	0	2	3	2
		b	41	14	7	16	19	12	13	13	13
	S.L.	a	5	4	x	5	2	5	3	1	5
		b	x	1	x	0	1	3	1	5	1
Miscel-laneous	E.	a	6	8	12	3	2	4	6	2	9
		b	3	5	18	2	1	3	1	0	1
	S.L.	a	4	3	6	4	3	6	10	4	11
		b	x	5	x	1	8	0	9	1	4
All Species	E.	a	374	515	303	452	568	246	268	429	410
		b	65	27	59	57	52	101	61	51	89
	S.L.	a	389	765	x	934	1126	951	523	781	464
		b	x	134	x	254	303	464	244	288	447

x = Results lost through damage to gear.

indicates significance at the 5 % but not at the 1 % level, and N.S., which indicates that there is no significant difference.

It will readily be seen from this table that in almost all cases, the three single comparisons considered in the analysis were highly significant, which indicates that marked differences in the catching capacities of the two vessels' gears were experienced for the different species of fish and that the use of a tickler-chain affected the catching capacities of the two nets. Furthermore, the significant interaction shows that the tickler-chain affected their catching capacities to different extents.

Although the analysis has demonstrated that the efficiencies of the two gears differed, it gives no indication of which vessel's gear was the more efficient sampling unit or whether the use of a tickler-chain increased or decreased the numbers of fish caught. This can, however, be gauged from a comparison of the mean logarithms of the catches of each species of fish. These, together with their 95 % confidence limits, are given in Table IV, and the antilogs of these means are graphed in Figure 1.

The confidence limits given for each species of fish represents the range of values on either side of the mean within which the true value

Table II. Logarithms of Numbers

			Day 1			Day 2			Day 3		
Plaice	E.	a	2·064	2·288	2·330	2·212	1·935	2·305	2·350	2·193	2·146
		b	0·000	0·477	1·176	0·778	0·669*	0·845	1·114	0·602	0·954
	S.L.	a	2·447	2·144*	2·305	2·233	2·286	2·097	2·377	2·240*	2·422
		b	1·623	1·643	1·931*	1·778	1·544	1·851	1·724	1·903	2·009
Dabs	E.	a	2·093	2·346	2·480	2·325	2·000	2·076	2·405	2·318	2·079
		b	0·699	0·903	1·114	1·041	1·040*	1·322	1·491	1·255	0·903
	S.L.	a	2·770	2·609*	2·477	2·748	2·708	2·738	2·666	2·798*	2·678
		b	2·248	2·190	2·282*	2·430	2·093	2·412	1·919	2·444	2·362
Gurnards	E.	a	1·799	1·568	1·322	1·699	1·633	1·544	1·544	1·580	1·623
		b	0·602	0·903	1·114	1·114	0·913*	0·477	0·903	0·699	0·903
	S.L.	a	1·230	1·565*	1·301	1·556	1·602	1·431	1·398	1·438*	1·447
		b	1·204	1·477	1·038*	1·544	0·954	1·279	0·699	1·301	1·204
Whiting	E.	a	0·954	0·778	0·301	0·903	0·000	0·477	0·000	0·000	0·845
		b	1·204	1·146	0·845	1·230	0·887*	0·954	0·903	0·778	1·322
	S.L.	a	0·000	0·486*	0·301	0·000	0·778	0·000	0·301	0·263*	0·301
		b	0·477	0·301	0·202*	0·000	0·000	0·699	0·477	0·778	0·778
Miscel-laneous	E.	a	1·230	0·477	1·114	0·477	0·845	1·491	0·699	0·477	0·699
		b	0·845	0·000	0·602	0·301	0·342*	0·301	0·602	0·699	0·301
	S.L.	a	1·000	0·833*	1·477	1·255	0·699	0·845	1·204	0·990*	0·845
		b	0·903	1·176	1·184*	1·079	0·845	1·415	0·602	0·954	1·255
All Species	E.	a	2·51	2·66	2·74	2·63	2·37	2·59	2·71	2·60	2·49
		b	1·45	1·46	1·67	1·64	1·55*	1·57	1·77	1·52	1·63
	S.L.	a	2·95	2·78*	2·74	2·89	2·88	2·85	2·87	2·85*	2·89
		b	2·38	2·38	2·45*	2·57	2·23	2·57	2·16	2·59	2·56

E. = "Explorer" S.L. = "Sir Lancelot" a = with tickler b = without tickler

1 = All species
2 = Plaice
3 = Dabs
4 = Gurnards
5 = Whiting
6 = Miscellaneous

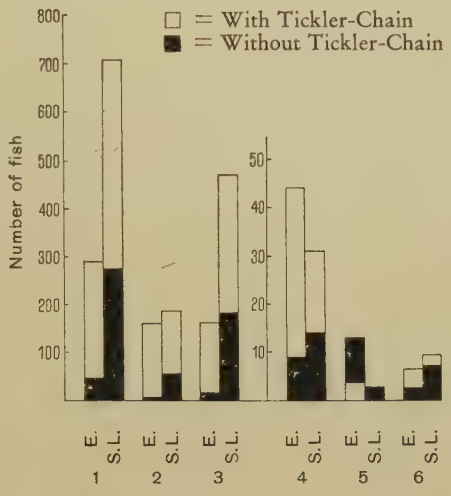

Figure 1.
Antilogs of mean log catches of each species caught by the "Explorer" (E.) and "Sir Lancelot" (S.L.).

of Fish caught in each Haul.

			Day 4			Day 5			Day 6			Total
Plaice	E.	a	2·117	2·310	2·093	2·274	2·512	1·903	1·886	2·400	2·362	39·680
		b	0·477	0·477	0·845	0·903	1·041	1·380	1·079	0·903	1·176	14·896
	S.L.	a	2·064	2·334	2·223*	2·396	2·480	2·352	2·053	2·307	2·182	40·942
		b	1·547*	1·580	1·715*	1·708	1·968	1·964	1·724	1·771	1·763	31·746
Dabs	E.	a	2·083	2·386	2·025	2·312	2·292	2·152	2·097	2·086	2·114	39·670
		b	0·954	0·301	1·204	1·415	1·079	1·771	1·301	1·362	1·613	20·768
	S.L.	a	2·364	2·686	2·607*	2·808	2·874	2·831	2·531	2·751	2·441	48·085
		b	2·059*	1·908	2·203*	2·301	2·294	2·548	2·233	2·324	2·568	40·818
Gurnards	E.	a	1·944	1·724	1·756	1·756	1·653	1·362	1·785	1·732	1·623	29·647
		b	1·079	0·778	1·146	0·903	1·079	0·778	1·255	1·000	1·342	16·988
	S.L.	a	1·342	1·699	1·649*	1·568	1·863	1·613	1·778	1·079	1·362	26·921
		b	1·242*	1·079	1·303*	0·699	0·845	1·279	1·114	1·176	1·230	20·667
Whiting	E.	a	1·505	1·041	0·903	0·477	0·602	0·000	0·477	0·602	0·477	10·342
		b	1·623	1·176	0·903	1·230	1·301	1·114	1·146	1·146	1·146	20·054
	S.L.	a	0·778	0·699	0·504*	0·778	0·477	0·778	0·602	0·301	0·778	8·125
		b	1·014*	0·301	0·489*	0·000	0·301	0·602	0·301	0·778	0·301	7·799
Miscellaneous	E.	a	0·845	0·954	1·114	0·602	0·477	0·699	0·845	0·477	1·000	14·522
		b	0·602	0·778	0·279	0·477	0·301	0·602	0·301	0·000	0·301	7·634
	S.L.	a	1·279	1·146	1·058*	0·699	0·602	0·845	1·041	0·699	1·079	17·596
		b	1·028*	0·778	0·937*	0·301	0·954	0·000	1·000	0·301	0·699	15·411
All Species	E.	a	2·57	2·71	2·48	2·66	2·75	2·39	2·43	2·63	2·61	46·53
		b	1·81	1·43	1·77	1·76	1·72	2·00	1·79	1·71	1·95	30·20
	S.L.	a	2·59	2·88	2·83*	2·97	3·05	2·98	2·72	2·89	2·67	51·28
		b	2·39*	2·13	2·43*	2·40	2·48	2·67	2·39	2·46	2·65	43·89

Values marked * estimated from data.

Table III. Analysis of Variance of catch

Source of Variation	Degrees of Freedom		Sums of Squares		Mean Square		Signif cance
Plaice.							
Explorer v Sir Lancelot	1		4·5562		4·5562		xx
Tickler chain v No Tickler	1	3	16·0367	23·9676	16·0367	7·9892	xx
Interaction	1		3·3748		3·3748		xx
Days	5		0·5614		0·1123		x
Times	2		0·2517		0·1258		N.S.
Day × Time Interaction	10		0·4291		0·0429		N.S.
Error	44		1·8485		0·0420		
Total	64		27·0584				
Dabs.							
Explorer v Sir Lancelot	1		11·2536		11·2536		xx
Tickler chain v No Tickler	1	3	9·5113	22·6450	9·5113	7·5483	xx
Interaction	1		1·8801		1·8801		xx
Days	5		0·7145		0·1429		x
Times	2		0·0942		0·0471		N.S.
Day × Time Interaction	10		0·2996		0·0300		N.S.
Error	44		2·2305		0·0507		
Total	64		25·9838				
Gurnards.							
Explorer v Sir Lancelot	1		0·0126		0·0126		N.S.
Tickler chain v No Tickler	1	3	4·9681	5·5505	4·9681	1·8502	xx
Interaction	1		0·5698		0·5698		xx
Days	5		0·2530		0·0506		N.S.
Times	2		0·0086		0·0043		N.S.
Day × Time Interaction	10		0·5038		0·0504		N.S.
Error	44		2·0572		0·0468		
Total	64		8·3731				

for the population mean will lie with 95 % certainty. Thus, the observed mean log catch of plaice by the "Explorer" using a tickler-chain was 2·204 with confidence limits ±0·097; giving the range within which the true mean lies of 2·107 and 2·301. From the table of means and confidence limits, it is possible to determine whether the difference between any pair of mean values is significant. For instance, the confidence limits of the "Explorer's" catch of plaice with a tickler-chain were 2·107—2·301, whilst the "Sir Lancelot's" catch of this species was 2·178—2·372. Thus, the ranges of the mean catches of plaice by the two vessels using tickler-chains show considerable overlap, which suggests that there is no significant difference between the mean catches of plaice by the two vessels. A similar comparison between the mean catches when a tickler-chain was not in use shows that the difference was very significant. A comparison of the difference between any pair of mean catches can be carried out using the "t" test. From a con-

each species of Fish.

Source of Variation	Degrees of Freedom		Sums of Squares		Mean Square		Significance
iting.							
lorer v Sir Lancelot	1	3	2·9089	5·5319	2·9089	1·8440	xx
kler chain v No Tickler	1		1·2236		1·2236		xx
raction	1		1·3995		1·3995		xx
rs	5		1·2620		0·2524		x
es	2		0·0554		0·0277		N.S.
× Time Interaction	10		1·1804		0·1180		N.S.
or	44		4·0893		0·0929		
Total	64		12·1191				
cellaneous.							
lorer v Sir Lancelot	1	3	1·6353	3·0858	1·6353	1·0286	xx
ler chain v No Tickler	1		1·1433		1·1433		xx
raction	1		0·3072		0·3072		x
s	5		1·2369		0·2474		x
es	2		0·4350		0·2175		N.S.
× Time Interaction	10		0·7782		0·0778		N.S.
or	44		3·2754		0·0744		
Total	64		8·8113				
l Catch.							
lorer v Sir Lancelot	1	3	4·7227	13·6471	4·7227	4·5490	xx
ler chain v No Tickler	1		7·8144		7·8144		xx
raction	1		1·1100		1·1100		xx
s	5		0·1815		0·0363		N.S.
es	2		0·0502		0·0251		N.S.
× Time Interaction	10		0·0991		0·0099		N.S.
r	44		0·9788		0·0222		
Total	64		14·9567				

sideration of the differences between the mean catches of each species of fish by the two gears, the following main differences between the catching capacities of the two gears are evident:—

(1) The "Sir Lancelot" completely outfished the "Explorer" for flatfish (plaice and dabs) but caught smaller quantities of roundfish (whiting) when neither ship used a tickler-chain.

(2) In the hauls with a tickler-chain the "Sir Lancelot" caught larger quantities of dabs than the "Explorer", but for all other species no significant differences between the catches were experienced.

(3) Increases in the catches of plaice, dabs, gurnards, and miscellaneous species were experienced with both ships' gears when a tickler-chain was used but the increase with the "Explorer's" gear was relatively much greater than with the "Sir Lancelot's".

(4) With the "Explorer's" gear, the use of a tickler-chain resulted

Table IV. Mean Log Catches of each Species.

	"Explorer"		"Sir Lancelot"		95 % Confidence Limits.
	With Tickler-Chain	Without Tickler-Chain	With Tickler-Chain	Without Tickler-Chain	
Plaice	2·204	0·828	2·275	1·764	±0·097
Dabs	2·204	1·154	2·671	2·268	±0·107
Gurnards	1·647	0·944	1·496	1·148	±0·103
Whiting	0·575	1·114	0·451	0·433	±0·145
Miscellaneous	0·807	0·424	0·978	0·856	±0·129
Total Fish	2·590	1·680	2·850	2·440	±0·071

in decreased catches of whiting when compared with the same gear without a tickler-chain.

The magnitude of the differences between the catches of the different species can be seen from Table V (page 168), which gives the ratios of the antilogs (minus 1) of the mean log catches contained in Table IV for the four most important comparisons.

Discussion.

Of the observed differences between the catches of the two gears, those for plaice and dabs are of the greatest magnitude. The "Explorer's" gear when used without a tickler-chain was relatively ineffective in sampling these two species, for which the approximate mean catches for a two-hour haul were 7 and 14 fish respectively, or approximately of the order of 1/10th of the mean catches of these species by the "Sir Lancelot". The catches of miscellaneous species also, which were made up largely of flatfish, were over twice as great with the "Sir Lancelot's" gear as with the "Explorer's" when no tickler-chain was used.

It will be seen from the description of the two nets used in the experiment that they differed particularly in the make up of their groundropes and bosom, which were much heavier on the "Sir Lancelot's" net than on the "Explorer's". The "Sir Lancelot's" net would therefore tend to keep in much closer contact with the sea-bed and cause greater disturbance of the sandy substratum than would the "Explorer's", with the result that flatfish lying or buried in the sand would be less likely to pass under its groundrope and thus evade capture. That the two nets did maintain different degrees of contact with the sea-bed throughout the experiment is borne out by the numbers of benthic invertebrates (*Asterias rubens* and *Asteropecten irregularis*) which were caught by the two gears. The mean numbers of these forms caught by the "Sir Lancelot" and "Explorer" in the without-tickler-chain hauls were 268 and 17 respectively. Previous work using the echometer to record the behaviour of the trawl in action (Wood and Parrish, 1950) has confirmed the tendency for a lightly rigged net such as the "Explorer's" to pass lightly over the sea-bed and at times to fish slightly above it.

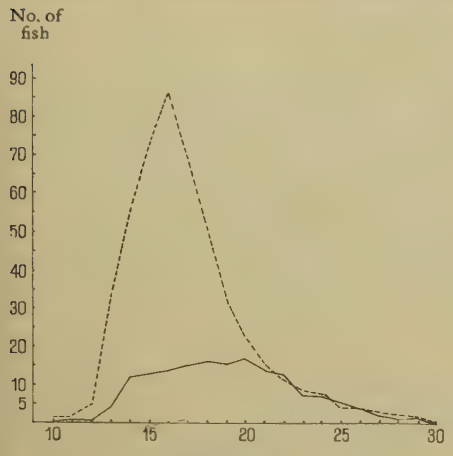

Figure 2.
Length Distribution of Dabs

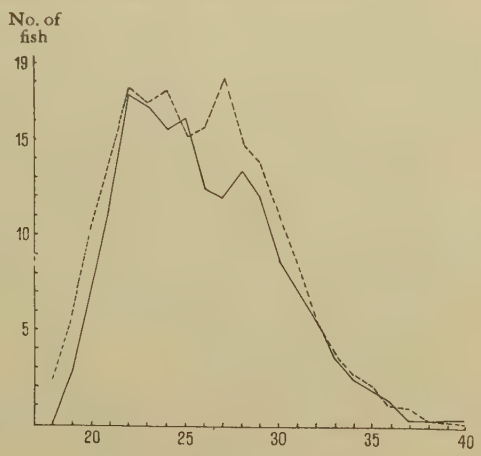

Figure 3.
Length Distribution of Plaice

(Centimetres, unsmoothed)

- - - - - - - = "Sir Lancelot", with Tickler-Chain.
——— = "Explorer", with Tickler-Chain.

The results also show, however, that the use of a tickler-chain on the "Explorer's" net caused a marked increase in its catching capacity for flatfish, particularly for plaice, the catches of which increased twenty-seven-fold over the no-tickler-chain catches. Furthermore, the use of this accessory gear raised its catching capacity to the same level as that of the "Sir Lancelot's", for which the tickler-chain produced a much smaller increase in efficiency. Although the increase in efficiency was very marked for dabs as well as plaice, the "Sir Lancelot's" catches of this species were still over twice as great as the "Explorer's" when both vessels used tickler-chains. It is probable, however, that this can be largely explained by a difference in the cod-end mesh size of the two nets. Although cod-ends of the same mesh size were taken aboard at the commencement of the experiment it was evident from measurements taken during the course of the trawling period that the meshes of the "Sir Lancelot's" nets had decreased in size due to shrinkage whereas there was no appreciable shrinkage in the "Explorer's"; consequently there was a difference in mesh size of approximately 10 mm. between the two nets throughout the greater part of the sampling period. The length frequencies of dabs in the catches show that the majority caught were within the size-range 12—20 cm., over which range mesh selection is operative, with the result that the smaller mesh of the "Sir Lancelot's" net would retain a greater percentage of these sizes than would the "Explorer's". The plaice catches, on the other hand, were mostly above the mesh selection range of the two meshes, so that no such marked effect would be noticed. These conclusions are borne out by a study of Figures 2 and 3 which give the size frequency polygons for dabs and plaice for the mean catches of the two gears. It is clear from these diagrams that the "Explorer's" and "Sir Lancelot's" catches of plaice when

a tickler-chain was used were of approximately the same length composition, whereas those of dabs showed a marked difference in the 12—20-centimetre range but no significant difference at the larger sizes.

It is evident therefore that the use of a tickler-chain on a lightly rigged net such as the "Explorer's" serves to disturb the fish lying on or buried in the sandy substratum, thus resulting in a decrease in the numbers escaping under the trawl. In view of the heavier groundropes and bosom on the "Sir Lancelot's" net the effect of the tickler-chain would be expected to be of less extent than with the "Explorer's", and it will be seen from Table V that it was approximately threefold for both plaice and dabs.

Table V. Ratios of derived mean Numbers of Fish.

	"Explorer" with Tickler / "Explorer" without Tickler	"Sir Lancelot" with Tickler / "Sir Lancelot" without Tickler	"Sir Lancelot" with Tickler / "Explorer" with Tickler	"Sir Lancelot" without Tickler / "Explorer" without Tickler
Plaice	27	3·3	x	9·5
Dabs	12	2·8	2·9	13
Gurnards	5·4	2·5	x	x
Whiting	0·3	x	x	0·2
Miscellaneous	2·5	x	x	3·0
Total Fish	8·4	2·6	1·8	6·0

The differences between the catches of gurnards by the two vessels are of interest in showing that for both vessels the use of a tickler-chain increased the numbers caught, and although the analysis shows no significant difference between the "Explorer's" and "Sir Lancelot's" catches when no tickler-chain was used, it only just failed to be significant at the 5 % level. It is evident therefore that gurnards, like flatfish, live in close contact with the sea-bed and may in fact become partially buried in the substratum.

The whiting catches show that as in the earlier experiment, the "Explorer's" gear was the more effective sampling unit for this species. In the hauls without a tickler-chain the "Explorer's" catches were approximately five times greater than the "Sir Lancelot's", but in view of the difference in cod-end mesh size, and the fact that the whiting were all within the mesh selection range of the "Explorer's" net, it is probable that the difference would have been greater if cod-ends of the same mesh size had been used. Of particular interest is the significant decrease in the catches of this species by the "Explorer" when a tickler-chain was used. This result indicates that the disturbing action of an accessory gear of this nature may cause active swimmers such as the whiting to avoid the net and escape before the mouth of the trawl reaches them. Further experiments on a more densely populated round-fish ground are needed, however, before the full extent of this effect can be determined.

Summary.

In this experiment the catching capacities of a roundfish trawl as used on northern North Sea grounds and a flatfish trawl as used in the southern North Sea have been compared and the effect of the use of a tickler-chain on the efficiencies of each has been assessed.

A randomized block design was adopted for the experiment and the results were analysed by the statistical analysis of variance method.

Marked differences between the catching capacities of the two nets were recorded for different species of fish. When the two trawls were used without a tickler-chain the heavier flatfish net caught approximately 10 times as many plaice and 13 times as many dabs as the lighter roundfish gear. When tickler-chains were used the catching capacities of these two species were approximately equal.

These differences are discussed in relation to the make-up of the two trawls.

The flatfish gear proved less effective in catching whiting than the roundfish one both with and without the use of a tickler-chain, but the catches of this species were significantly less for the latter gear when a tickler-chain was used. Further tests on the effect of the use of tickler-chains on roundfish catches are recommended.

Acknowledgements.

I wish to express my thanks to the Scientific Staff of the Fisheries Laboratory, Lowestoft, for making their research vessel "Sir Lancelot" available for this experiment, to Mr. A. R. Margetts for his co-operation in its planning, and to the ship's company and scientific personnel for their co-operation in carrying out the work at sea. Thanks are also due to Mr. M. H. Quenouille and Mr. W. Boyne of the Statistics Department, Marischal College, Aberdeen, for their help in the analysis of the results of the experiment.

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APPENDIX.

(1) Calculation of missing items.

The values determined for the hauls lost due to damage to gear etc. have been calculated from the data by a method which gives to each item its expected value, thereby reducing the "error" sums of squares in the analysis of variance to a minimum. The formula by which each item is calculated is as follows:—

$$X = \frac{tT + bB - S}{(t-1)(b-1)}$$

where X = missing item.
t = number of treatments.
b = number of blocks.
T = sum of items with same treatment as missing item.
B = sum of items in same block as missing item.
S = sum of all items.

If X_1 and X_2 are two missing items, a reasonable value of X_2 is first chosen (the experimental mean), and X_1 is then calculated using the above formula. The calculated value of X_1 is then used for an estimation of X_2. X_1 is then recalculated using the new X_2 value. This cycle is repeated until no change in the calculated values is experienced. The same procedure is adopted for more than two items.

The values calculated in this way are used in the analysis of variance in the normal way except that for each value, one degree of freedom is deducted from the "total" and "error" components of variability.

(2) Analysis of Variance.

The subdivision of the degrees of freedom in the analysis of the results of this experiment are given below together with the sources of variation.

Source of Variation	Degrees of Freedom
Nets	3
Hauls	17
Net and Haul Interaction = Error	44[1])
Total	64[1])

[1]) 7 degrees of freedom subtracted for estimated values of missing items.

The "Hauls" variability can be further subdivided into that due to differences in the daily totals, that due to the differences in catches at different periods of the day, and that due to the interaction of these two effects. In this manner, the analysis table becomes:—

Source of Variation		Degrees of Freedom
Hauls (17)	Nets	3
	Days	5
	Times	2
	Day × Time Interaction	10
Error		44
Total		64

The "Error" variability, which is in fact made up of the two first order interactions, Net × Day and Net × Times, and the second order interaction Net × Day × Time, gives a measure of the magnitude of the variation in the number of fish caught as a result of the uncontrollable random factors, and provides a measure of σ^2 against which the variability due to the nets may be tested for significance. This has been carried out by the variance ratio or "F" test as in normal statistical practice. Details of the method are given in "Statistical Methods" by Snedecor.

(3) Stages of Calculation.

The calculation of the sums of squares for the different components of variability are as follows:—

(i) Total Variability.

Sums of Squares	Degrees of Freedom
$Sx_i^2 - \frac{(Sx_i)^2}{N}$	$N-1$

(ii) Hauls.

Sums of Squares	Degrees of Freedom	Mean Square
$\frac{(Sx_{H_1})^2 + (Sx_{H_2})^2}{n_H} + \ldots - \frac{(Sx_i)^2}{N}$	$H-1$	$\frac{1}{H-1}\left(\frac{(Sx_{H_1})^2 + (Sx_{H_2})^2}{n_H} + \ldots - \frac{(Sx_i)^2}{N}\right)$

(iii) Nets, Days, Times.

Sums of Squares	Degrees of Freedom	Mean Square
$\frac{(Sx_A)^2 + (Sx_B)^2}{n_t} + \ldots - \frac{(Sx_i)^2}{N}$	$E-1$	$\frac{1}{E-1}\left(\frac{(Sx_A)^2 + (Sx_B)^2}{n_t} + \ldots - \frac{(Sx_i)^2}{N}\right)$

(iv) Day × Time Interaction.

Sums of Squares	Degrees of Freedom	Mean Square
Hauls sum of squares — Day plus Time sums of squares	$(D-1)(T-1)$	$\frac{1}{(D-1)(T-1)}\left(\text{Sum of squares}\right)$

(v) Error.

Sums of Squares	Degrees of Freedom	Mean Square
Total sum of squares — Hauls sum of squares	$(N-1)(H-1)$	$\frac{1}{(N-1)(H-1)}\left(\text{Sum of squares}\right)$

Where x_i = single observation.
Sx_{H_1} = sum of catches for Haul 1.
Sx_A = sum of catches for each net or at each time or on each day.
N = total number of observations.
n_H = number of observations in each haul.
n_t = number of observations with each net etc.
H = number of hauls.
E = number of nets.
D = number of days.
T = number of times.

Herring Spawning Grounds off the South Coast of Iceland during Spring 1950.

By

A. Fridriksson and **G. Timmermann.**

I. Introduction.

It has been known for a long time that herring spawn in Icelandic waters. In 1903 Schmidt succeeded in showing that the spawning is limited to the southern part of the coast (Schmidt 1904), as the smallest larvae were found there only. Since then herring larvae have repeatedly been taken in plankton hauls (Jespersen 1920, Tåning 1936).

In 1905 Sæmundsson was able to distinguish two groups of herring, a spring spawning and a summer spawning one (Sæmundsson 1906). This finding was later confirmed by A. C. Johansen, who carried out racial investigations on both groups (Johansen 1919 and 1921). In this paper, only the spring spawners are dealt with.

In 1944 Friðriksson reviewed the literature and concluded that the spawning of the spring herring took place along the entire south coast from Eystra-Horn to Reykjanes and perhaps off the south-west coast to Breidafjord, but chiefly off the middle and western parts of the south coast; further that spawning took place during February-April, most probably within the 75 m. depth contour, principally, perhaps, at about 50 m. depth. The localities of spawning were not known in detail (Friðriksson 1944).

During the autumn of 1934 a search for these spawning grounds was planned. Inquiries were made among the fishermen of the Westman Islands for "spawny" haddock and other indications of herring spawning, but without any positive results. The experiments were carried out during the springs of 1935 and 1936. In 1935, 89 bottom samples were taken and a herring trawl was operated in 88 localities, but in spite of every effort, both then or in 1936, no evidence of spawning could be obtained (Friðriksson 1944).

II. Material and Methods.

During recent years herring have appeared in unusually great density off the south and south-west coasts of Iceland, giving rise to an entirely new fishery in the inlets of Faxa Bay in November-February of the years 1946—1947 and 1947—1948. A large part of this stock was found to belong to the spring spawning tribe and it was therefore thought worth while to make a new attempt to locate the spawning grounds. Recently the distribution of the larvae has been successfully charted by Dr. H. Einarsson, and attempts to approach the question from new angles were made last spring by the authors.

Figure 1. The regions investigated.

The black dots indicate the shore stations at which haddock stomachs were examined: these are, from east to west, Hornafjördur, Westman Islands, Eyrarbakki, Sandgerði, Keflavík, Reykjavík (trawls), and Akranes. The material was obtained in the areas indicated by white rectangles. The black areas show where bottom samples were taken.

III. The Investigations.

1. Bottom Samples.

The Petersen 0·2 m². bottom grab was used. The samples were labelled and preserved for investigation in the laboratory. As shown in Figure 1, 5 different areas were sampled: a) around the Westman Islands; b) on Selvogsbanki; c) west and north of Reykjanes; d) in the southern part of Faxa Bay, and e) in the northern part of Faxa Bay. Where the sea bottom was hard or rocky it was very difficult to get any material at all and in many cases we got nothing.

The sampling off the Westman Islands was carried out during the period 27. March—3. April; on Selvogsbanki on 13. April, and all the collection of bottom samples north of Reykjanes was done from 23. to 29. April. The total number of samples taken was: a) 43, b) 4, c) 110, d) 110, and e) 110, or 377 samples in all.

Herring spawn was found only in the area round the Westman Islands (Fig. 3) where 8 samples gave positive results, the number of eggs per sample ranging from 1 to 330, corresponding to 5 to 1650 eggs

per m^2. The following table gives the particulars for the positive stations.

	Date	Locality	Depth in metres	Nature of bottom	Number of eggs
1.	27.3.50	63°22·4′N. 20°19·4′W.	ca. 70	black sand and gravel	2
2.	—	63°22·0′N. 20°19·5′W.	ca. 70	—	225
3.	—	63°22·2′N. 20°20·5′W.	ca. 60	—	330
4.	—	63°27·7′N. 20°24·6′W.	78	—	9
5.	3.4.50	63°25·1′N. 20°26·0′W.	75	—	35
6.	—	63°22·7′N. 20°25·7′W.	55	—	1
7.	—	63°20·9′N. 20°25·6′W.	75	—	1
8.	—	63°21·2′N. 20°30·5′W.	90	—	1

The depth ranged from 55 to 90 m. and the sea bottom consisted of dark, coarse sand, the eggs being glued to the largest sand particles, which were only some few mm. in diameter (Fig. 2).

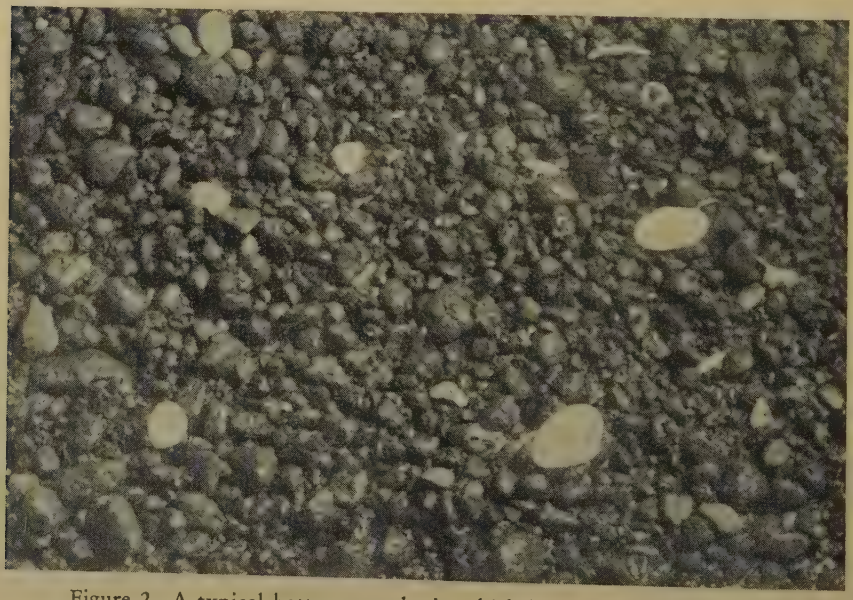

Figure 2. A typical bottom sample, in which herring eggs were found. Similar material was found in haddock stomachs which contained spawn.

If we compare these results with those obtained by Runnström on the spring spawning grounds in Norway (Runnström 1941) an outstanding difference in quantity is evident. In Runnström's material about every third sample contained herrings' eggs and in 9 % of the positive cases the quantity of eggs per m^2. was one litre or more, whereas the largest quantity found by us amounted only to 4 cc. (1650 eggs).

2. "Spawny" Haddock.

The occurrence of spawny haddock has been successfully employed in many countries as a method of tracing the localities of herring spawning. Bowman dealt with 85 cases of spawny haddock along the coasts of Scotland in 1921, and 49 cases in 1922 (Bowman 1923). He also found herring spawn in the stomachs of codling, saithe, and whiting, and in some cases herring eggs were deposited on fishing gear. Similar investigations were made by Hodgson in the southern North Sea during 1921—1927, when 79 cases of spawny haddock were recorded. He also found herring spawn in cod and dab, on nets and crab-pots, and in one case spawn was found in the cod-end of a trawl. Spawny haddock have also been found off northern Norway (Aurich und Stier 1939, Manteufel and Marty 1939).

Haddock stomachs were collected in the following fishing ports (see Figure 1):—

Hornafjord	27 samples	270 stomachs
Westman Is.	96 —	960 —
Eyrarbakki	13 —	130 —
Sandgerði	21 —	210 —
Keflavík	18 —	180 —
Akranes	14 —	140 —
Trawlers (Reykjavik)	12 —	127 —
Total	201 samples	2017 stomachs

No herring spawn was found in the samples from Hornafjord, Sandgerði, Keflavík, and Akranes. However, it should be mentioned that all the spring fishery in these places was with long-lines, a gear which is not suitable for catching spawny haddock. In Eyrarbakki only 3 samples out of 13 turned out to be positive.

The most successful results were obtained by examining the samples collected in the Westman Islands. The gear principally used there in the fishery is gill-nets (bottom nets), long-lines, danish seines, and otter trawls. Haddock are only exceptionally taken in stand-nets, which are specially designed for cod, and it soon became evident that it was almost hopeless to expect spawny haddocks in long-line catches. 96 samples (960 stomachs) were examined, taken by the following gear:— long-line, 6 samples; danish seine, 65 samples; otter trawl, 10; and not specified, 15 samples.

The material was collected in the period 27. March—21. May and

came from depths ranging between 50—125 metres, but in some instances single samples were taken in shallower water.

The following table shows the frequency of occurrence of herring spawn in haddock stomachs.

Period (1950)	Number of samples (10 stomachs in each)	Number of positive samples	Percentage of positive samples	Average number of positive stomachs in the positive samples
27. March— 3. April	26	13	50	4·2
5. April —22. April	35	13	37	2·7
24. April —11. May	24	8	33	1·3
12. May —21. May	11	2	18	8·5
Total and/or Average	96	36	37·5	3·3

Thus, 36 samples out of 96, or more than every third sample (37·5 %) could be regarded as positive.

In some of the positive samples eggs were present in all the stomachs, in others in some only, and in a few samples eggs were present in only one stomach (last column of the table). The average number of positive stomachs in the positive samples is 3·3, or every third stomach. Altogether 116 positive stomachs were recorded, amounting to 12·1 % (or every 8th stomach) of the total number examined (960). It is also worth noting that for the first period 50 % of the samples are positive. After that time, the relative number of positive samples decreases con-

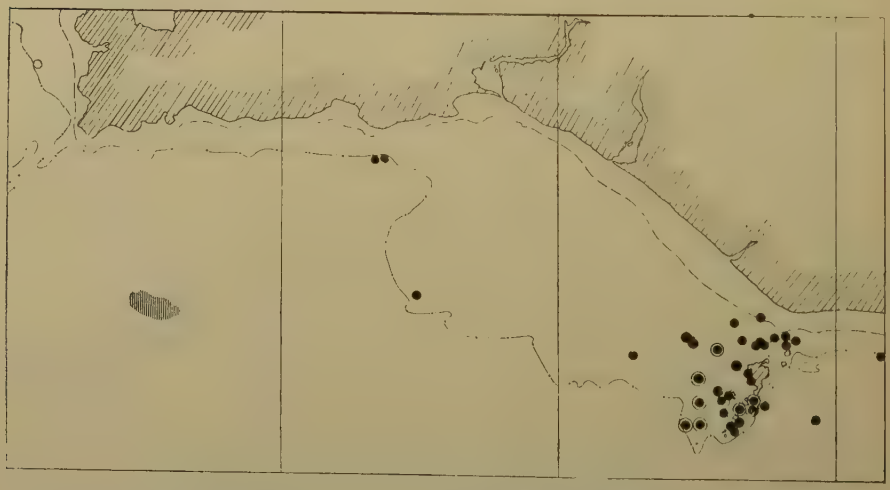

Figure 3. The spawning grounds recorded.

⊙ = spawn on the sea bottom
● = spawn in haddock stomachs
|||||| = spawning herring
○ = occurrence of "spawny" haddock, according to information from fishermen.
— — — — 50-m. depth contour; — · — · — · — 100-m. depth contour.

stantly, reaching its lowest value (18 %) about the middle of May. Simultaneously the average number of positive stomachs in the positive samples decreases.

The following table shows the number of eggs in the positive stomachs.

Period (1950)	Number of positive stomachs	The number of stomachs containing eggs 1— 10 eggs	11— 100 eggs	101— 1000 eggs	>1000 eggs
27. March— 3. April	54	4	8	21	21
5. April —22. April	35	6	16	8	5
24. April —11. May	10	3	3	4	0
12. May —21. May	17	0	12	5	0
Total	116	13	39	38	26
Percentage	100·0	11·2	33·6	32·7	22·5

In 44·8 % of the stomachs the quantity of eggs was relatively insignificant, there being less than 100 eggs in each. On the other hand 22·5 % contained considerable amounts of spawn, more than 1000 eggs

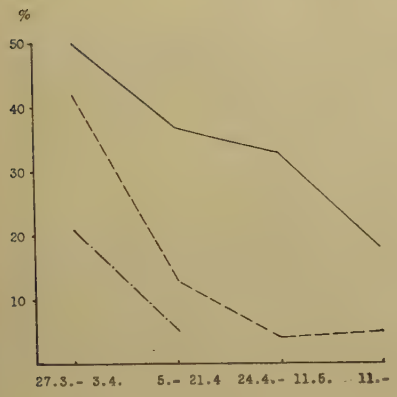

Figure 4. Quantity of herring eggs in haddock stomachs from the Westman Islands during the period 27. March to 21. May 1950.

——— Percentage (%) of positive stomachs,
– – – Number of stomachs containing more than 100 eggs,
·–·–· Number of stomachs containing more than 1000 eggs.

or several cc. per stomach. In single instances 12,000 to 15,000 eggs were recorded, corresponding to 30—35 cc. The table shows, too, that the number of stomachs containing high numbers of eggs decreased with time, the largest quantities being found almost entirely in March. This diminution of the occurrence of spawn is in good accord with what has already been said about the decrease in number of both positive samples and positive stomachs through the season.

In all positive stomachs a considerable amount of black, coarse sand was noticed: the haddock had obviously been compelled to eat the sand too, in order to get the spawn. The presence of this sand in the stomachs often served as an indicator of spawn, especially when only few eggs were present.

A sample of haddock stomachs, collected by a trawler (the "Hallveig Fróðadóttir") on Selvogsbanki (63°33′N., 21°30′W.) in 60—65 fathoms

(108—117 m.) on 15. April, is particularly interesting. The bottom was rocky with muddy or sandy patches. There were 12 stomachs in the sample, and all the stomachs were distended with spawn. One of them contained about 100 cc. which corresponds roughly to 40,000 eggs, or the whole of the spawn from two herrings. If all the eggs from this single stomach had escaped other dangers and survived, the quantity of adult fish would amount to about 130 hectolitres. The eggs had evidently been spawned quite recently, as the embryos were only little-developed and the eyes were not yet pigmented.

3. Spawning Herring.

There was no herring fishing during spring, but we succeeded in securing three samples of herring caught by chance. One, taken in a trawl between the Westman Islands and Portland about 1. March, consisted of 1027 herrings, the majority of which were spring spawners, not yet ready to spawn. The remainder were summer spawners in an early stage of maturity. Another sample, which originated from Jökuldjúp, Faxa Bay, had been caught in drift-nets on 23. Maj. This was also a mixture of the two groups, spring spawners, mostly in stage VII, and summer spawners, mostly in stage V.

The third sample, which was taken in a trawl 17—18 miles S.S.E. of Reykjanes (on Selvogsbanki) on 8. April, consisted of 134 herrings. These herrings were pure spring spawners, and actually spawning, as the following figures show:—

37 herrings were in stage V (ripe)
84 herrings were in stage VI (spawning)
13 herrings were in stage VII (spent)

In connexion with this sample, two main features are worthy of note. The average length of the herring in the sample was only 31·11 cm., that is, about 4 cm. less than that of the north coast herring. A single fish just reached a length of 35 cm., which is the average of the north coast herring. The smallest fish, a male in stage VI, was only 27 cm.

4. Information from Fishermen.

A questionnaire was circulated to a number of reliable fishing skippers in the Westman Islands. The results of inquiries, as regards the spring spawning, can be shortly summarized as follows:—

(a) The "whitening" of the sea by the milt, a phenomenon well known on the Norwegian spring spawning grounds, has never been observed.

(b) Spawn has been observed on fishing gear, but it is not clear whether or not it was herring spawn.

(c) Herring eggs have only been seen in the stomachs of witches and haddock, particularly the latter. Spawny haddock were well known to everyone of our informants.

(d) The principal localities in which spawny haddock are caught

were pointed out (see the chart, Fig. 5). When spawning, the herring seem to come in batches to the spawning grounds. They disappear after one or two days, pursued by the cod, whereas the haddock remains on the spot gorging the spawn.

(e) The depth limits for the spawning grounds seem to be about 35 and 55 fathoms (64—101 m.), but it should be pointed out that spawning occurring nearer inshore might escape attention owing to the lack of fishing there. On the other hand the boats work in depths of 80 fathoms. One of the indicators of the presence of herring is the gannet. It is never seen diving for the herring on the spawning grounds known to the fishermen. On the contrary, it hunts mainly over rocky bottoms, where indeed the principal spawning might take place, but we have no information on that point.

Figure 5. Herring spawning grounds off the Westman Islands, according to information from fishermen.

(f) Where spawny haddock are caught, the sea bottom is covered with dark sand.

(g) As to the time of spawning, it is evident that no spawning took place in February 1950. One of our informants was able to record the date when he first caught spawny haddock, namely, 15. March, in both 1949 and 1950.

(h) It was the general impression that the herring had occurred in larger quantities, and more regularly, during recent years than previously. They seemed to be more plentiful in 1950 than in any earlier year. Great shoals were recorded on echo-sounders and herring were frequently hooked on long-lines.

IV. Conclusions.

During the period 27. March to 21. May 1950 herring spawning off the western end of the south coast of Iceland was recorded in 48 cases. Herring eggs were found on the sea bottom in 8 localities, 39 samples of haddock stomachs containing herring spawn were examined, and one sample of spawning herring was investigated.

In the spring of 1950 herring spawning has taken place in an area bounded on the east by the Westman Islands and very probably extending to the most westerly edge of Eldeyjarbanki, west of Reykjanes. The distribution of the spawn is by no means uniform, but is patchy.

Spawning began about the middle of March and lasted until toward the end of May. We do not know to what extent spawning may have taken place eastward of the Westman Islands, and no traces of spawning were found north of Reykjanes. Information on spawning on rocky bottoms is lacking. In every locality in which herring eggs were present, either free or in stomachs of haddock, the surface of the sea bottom consisted of coarse sand. The depth range of spawning extends from

shallow water down to about 200 m. or even more, but the main spawning takes place between 50 and 100 metres.

It has been pointed out by Runnström (1941) that the spawning localities may change from year to year, as a result of changes in the hydrographical conditions. On the other hand, Bowman (1923) came to the conclusion that the same spawning grounds were used both by spring and autumn spawners year after year. Our investigations, which only cover a single season, provide no evidence on this point. However, a certain conservatism in selection of spawning grounds might be expected, as the hydrographical conditions off the western end of the south coast in spring do not vary to any considerable extent.

It is not easy to explain why the experiments carried out in 1935 and 1936 were so entirely unsuccessful. At that time no information on spawny haddock was available. The reason might be that at that time there was no trawl or seine-net fishing in spring, the only gear used being long-lines, which do not take spawny haddock in any appreciable quantity, and gill-nets (bottom nets), which hardly catch any haddock at all. It must be noted, however, as an outstanding feature that no spawn was taken with the bottom grab, in precisely the same places in which positive samples were obtained in 1950. The general impression that herring are much more numerous now than previously should also be borne in mind. The large-scale occurrence of herring off the south and south-west coasts of Iceland during recent years certainly indicates a period of rich stocks, in contrast to the years about 1935—1936.

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"Condition Rings" on Scales of the European Pilchard, *Sardina pilchardus* (Walbaum).

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Introduction.

Z a m a k h a e v (1940) described what he called "spawning marks" on scales of shad (*Caspialosa* spp.) from the Caspian Sea. The marks are formed in the years of life at which the shad are believed to be sexually mature, and at the spawning seasons. They are very sharp, and most conspicuous on scales from the middle of the trunk. Sometimes such a mark appears to be superimposed upon an earlier ring of the ordinary clupeid scale type, obliterating it except in the apical portion. To explain these phenomena, Z a m a k h a e v postulated a breaking-off of the dorsal and ventral edges of scales in the mid-trunk region, as a result of the shrinking of skin following reduction of girth (loss of body fat) at spawning time.

The present author (B l a c k b u r n 1949, Section III, 1a and 3) found similar marks on scales from the ventral part of the mid-trunk section of the flank of the Australian pilchard, *Sardinops neopilchardus* (Steindachner), from New South Wales. The marks are formed in autumn and winter, when the pilchards of that region spawn, and when they contain much less fat than in summer; and at ages approximately corresponding to those at which the fish are sexually mature. The interference with the previously formed ordinary ring of the same year, noted by Z a m a k h a e v, also occurs. The marks were provisionally called "spawning rings". The ordinary rings, which are formed annually throughout the whole life of the fish, were called "yearly rings".

In a later paper (B l a c k b u r n 1950, Section II) this author dealt further with the matter for the Australian pilchard, this time with a larger material from Victoria. In that region the species spawns in spring and summer, when the fat content is again low. This is the season at which the marks in question are formed. Broken edges can be

found on some scales taken at that season. Interference with the yearly ring is again sometimes seen, but quite commonly the two are separated (presumably because of fast spring and summer growth at the scale-margin), forming an annual pair. An examination of scales from seven body-areas of each of 20 fish showed that the marks are most conspicuous on scales from the mid-trunk section. Elsewhere they are often like the yearly rings, so that there are sometimes two ordinary rings for a year's scale-growth. This showed that the mid-trunk scales were the most reliable for age-determinations.

However, there are sometimes no sharp "spawning rings" on even mid-trunk scales of spent fish, or of fish which, from their ages, would be expected to be mature; but these scales sometimes bear pairs of ordinary rings which can be identified as annual pairs like those on scales from the other body areas, the "spawning rings" simulating yearly rings. These cases mostly concern the earlier years. An instance of "spawning ring" formation was also found on the scales of a fish which was probably virgin. All this does not seriously affect Z a m a k h a e v' s main hypothesis, which, with modifications, was adopted for the Australian pilchard. It was recognized that loss of condition, important enough to be likely to cause fracture of scale-margins in the way envisaged by Z a m a k h a e v, would not necessarily occur in the same years of life as sexual maturity: but, as the correlation remained fairly good in the Australian pilchard material, it was convenient to go on speaking of "spawning rings".

H i c k l i n g (1945) had already shown for the European pilchard, *Sardina pilchardus* (Walbaum), which he studied at Cornwall, that the season of greatest loss of weight and fat is the end of winter, whereas spawning occurs in summer. He also stated that the scale-rings are formed in winter: but, as he only used the scales of the smaller fish, it seemed possible that his findings referred to the yearly type of ring and not to the other, and in any case it was not evident from the literature whether or not both types of ring occurred in this species.

By courtesy of Dr. W. C. Hodgson, the writer has now been able to study scales of Cornish pilchards, mainly from collections at the Lowestoft laboratory of the English Ministry of Agriculture and Fisheries. The observations that follow bear on the origin of the type of ring discussed above, and the interpretation of Cornish pilchard scales for age-determination.

Material.

In all, 1780 scales from 940 fish were examined from the Lowestoft collections. They were the laboratory scale samples M. 1-7 (November 1947), PV. I. (9. February 1948), PN. I (9. September 1948) and PW. 4 (4. July 1949). Another 280 scales were examined from 20 pilchards caught off St. Austell Bay, Cornwall, on 10. August 1950: two scales were taken from each of seven body areas on each fish.

These body areas were the same as those distinguished by the writer in his 1950 paper, namely: 1 and 2, respectively the dorsal and ventral

halves of the part of the flank anterior to the pectoral fin tip; 3 and 4, respectively the dorsal and ventral halves of the flank between pectoral fin tip and posterior end of the dorsal fin; 5 and 6, similar halves of the region between the dorsal and anal fins; and 7, posterior to the anal fin origin. The scales in the Lowestoft collections were taken mostly from area 1, sometimes from areas 2 and 3. The area preferred and used by the writer for Australian pilchard scales was area 4.

Observations on the scale-rings.

It was soon evident that many Cornish pilchard scales have both types of ring recognized in the Caspian shad and Australian pilchard material — those of the yearly type and those of the type previously called "spawning rings". The latter are henceforth called "condition rings", for reasons which will appear later.

The difference between the two kinds is perhaps most obvious in Figure 1 (the first, or innermost, ring compared with the others) and Figure 8 (the first two compared with the others). For finer details of condition ring structure, reference should be made to photographs in the papers by Z a m a k h a e v and B l a c k b u r n. Portions of Z a m a k h a e v' s description of this type of ring are "The ring appears to cut into the surface of the scale and interrupts sharply the rows of striae . . ." and "Beyond the 'ring of break', especially on the sides of the scale, there is a narrow bright stripe without striae. In some places wider stripes without striae are formed, or stripes with faintly visible and separated striae . . .".

Some rings seem intermediate in appearance between yearly and condition rings, having the appearance of "cuts" on the scale surface without the unstriated or incompletely striated border, or (more commonly) having the border but not being particularly sharp. An example is the second ring in Figure 11, the first and third being typical yearly and condition rings respectively.

An attempt was made to classify the rings (excluding partly obliterated ones) of 285 fish into yearly, intermediate, and condition types. Of 285 first rings, the three groups accounted respectively for 95, 5, and nil per cent.; of 283 second rings, 40, 39, and 21 per cent.; of 256 third rings, 7, 22, and 71 per cent.; of 222 fourth rings, 3, 10, and 87 per cent.; of 121 fifth rings, 1, 6, and 93 per cent.; of 42 sixth rings, nil, 3, and 97 per cent.; while 26 older rings were almost all condition rings. The first ring is almost always yearly, the second varies but is normally not clearly of the condition type, and the third and particularly the later rings are overwhelmingly of the condition type.

At first sight it appeared possible to link these findings with those of H o d g s o n and R i c h a r d s o n (1949) on the prevalence of mature Cornish pilchards in successive age-groups. They found that no fish with two growth-zones (i.e., one ring) on their scales had spawned, while a few at a year older were nearly ready for spawning, and many of those at a year older still had actually spawned. But any lingering idea that the sharp rings registered spawnings was soon dispelled; a few

virgin fish had scales which bore such rings, and it was found that such rings could be formed well before the spawning season.

It was possible to find scales with the condition ring clearly forming at the dorsal and ventral edges. The edges were irregular and sometimes roughly serrated, often with the irregularities filled in with new unstriated or weakly striated material — the "stripe" of Zamakhaev, in process of formation. Figure 1 shows something of this on the left; the scale is from a February fish. Of the 489 fish in the November samples, with 3 or more rings, 4 (0·8 %) had a condition ring definitely at the edge; of the 114 such fish in the February sample, 16 (14·0 %) showed the same thing; of the 36 such fish in the July sample, 6 (16·7 %) showed it; while of the 80 such fish in the September sample, none showed it. The yearly record is therefore incomplete, and more material collected during the first half of the year would have been valuable; but this was not to be had because the season of availability of the Cornish pilchard is mainly August to October (Hickling 1945). However, the data show that the formation of the sharp rings is definitely not confined to the spawning season. According to Corbin (1947, 1950, and references there), pilchard eggs are found in the English Channel and Celtic Sea mainly from April to November, with maximum occurrences in May and June; occasionally they occur in March and December, but not in January and February. The preceding observations show that the ring in question is often formed by early February.

The partial obliteration of a yearly ring by the condition ring of the same year, which seems to be the phenomenon that De Buen (1937, p. 381) styled "casquette" in the same species, is evident on some Cornish pilchard scales. In Figure 2 there are two plain yearly rings closest to the centre, and beyond that (clearest on the left side) three condition rings; but just inside the innermost condition ring there is another ring of the yearly type, which is not overlapped by the condition ring on the left side of the scale, or in the apical portion, although on the other side of the scale it joins the condition ring. This is not typical, but it shows what has happened on other scales where there is overlapping on both sides, so that certain rings appear to be duplicated in the apical portion only. This "casquette" is seen in the fourth and fifth rings in Figure 6, the third and fourth in Figure 8 (see upper left side), the third in Figure 9 (see upper left side), and in other instances. "Casquette" is not found with every condition ring, and it would not be expected, because in this fish the two rings may both be formed in winter when there is little growth at the scale-margin; this could cause complete obliteration of the yearly ring. That situation also occurs in the Australian pilchard in New South Wales, but in Victoria, as already mentioned, the other extreme is commonly reached; that is, the two rings are quite separate all round the scale, as the ring-forming season is also the growing period.

In the Cornish pilchard, however, the condition rings may interfere with one another as well as with yearly rings, a situation which was rarely found in the Australian species. In Figure 3 the third ring is a

condition ring and shows casquette, but in Figure 4, which shows another scale from the same fish, the two rings involved in the casquette are separate on the right side, where they are seen to be both condition rings. If the first scale only had been available, it would have been identified as having passed only three ring-forming seasons, but the second scale shows the fish to be a year older.

It was therefore important to investigate this new type of ring interference on scales from all parts of the fish.

The scales in Figures 5, 6, and 7 are from different areas of the same fish. The first scale (area 1) shows five rings, the number being clearest on the right side (there is casquette with the fourth and fifth, but it is hard to see in this photograph); the first three are yearly and the other two intermediate. The second scale (area 3) shows the same number of rings, the casquettes being clear, but the last three rings can now all be classified as condition rings. The third scale (area 4) shows five rings on the left side but only four on the right, as the fourth is superimposed upon the third. The scales from area 5 of this specimen were like those of area 4, and the others like those of area 3.

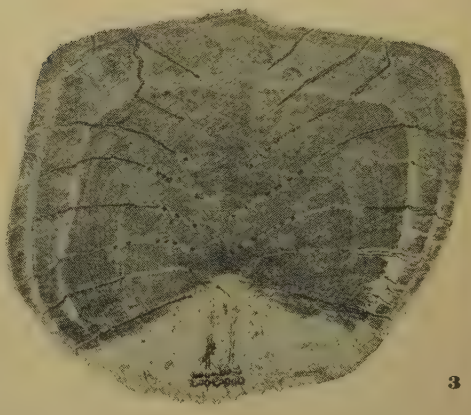
Figures 8, 9, and 10 show scales from different parts of another pilchard. In the first one (area 1) there are four rings, the first two being yearly and the next two being condition rings with casquettes. In the next scale (area 4) the second ring is intermediate, and the total number is still four on the left side; but on the right side it is only three, the outer condition ring being superimposed upon the one before. The third scale (area 6) shows only three on both sides. The scales of area 5 were like those of area 6, and the others resembled those of area 4.

For another specimen, Figures 11 and 12 again show scales from different parts. The former (area 1) shows five clear rings at the left side, and there is a sixth which is hard to see except at the upper corners; the first and second are yearly and the others (possibly excepting the last) are condition rings (the fourth has casquette). The other scale (area 4) shows the second ring now intermediate in type, and very marked interference between the third, fourth, and fifth, so that only two of these three are clear on either side. The scales of area 6 were like those of area 4, and the others like those of area 1.

Other sets of scales gave similar results. It is evident, firstly, that the scales of the mid-trunk region (areas 4, 5, and 6) tend to have the rings more sharply marked than those from the anterior and posterior regions; and secondly, that the condition rings on the scales of the mid-trunk region tend to interact, not only with their accompanying yearly rings (as they also do on other scales), but with one another. The advantage of the first is more than offset by the disadvantage of the second, for making age-determinations. In the Australian species the first tendency was most evident, but the second was little evident (see note at end of paper); and as it was very helpful to be able to distinguish yearly and condition rings, the mid-trunk scales were always used. But in the Cornish pilchard, as the mid-trunk scales would frequently give low readings, and as the types of rings are usually fairly clear on the other scales (more so than in the Australian species), the latter scales are better.

1

2



3

Figure 1. Scale of Cornish pilchard 212 mm. total length, no. 31 of sample PV. 1 in Lowestoft laboratory collection, collected 9. Feb. 1948: first ring of yearly type, next three of condition type, another condition ring at edge (see left side).

Figure 2. Scale of Cornish pilchard 202 mm. total length, no. 53 of sample M. 2 in Lowestoft laboratory collection, collected 11. Nov. 1947: first two rings of yearly type, next three of condition type, the first condition ring having a yearly ring just inside it on the left side and in the apical region.

Figure 3. Scale of Cornish pilchard 193 mm. total length, no. 79 of sample M. 2 in Lowestoft laboratory collection, collected 11. Nov. 1947: first ring of yearly type, next two of condition type, the last with portion of another ring included in the apical region.

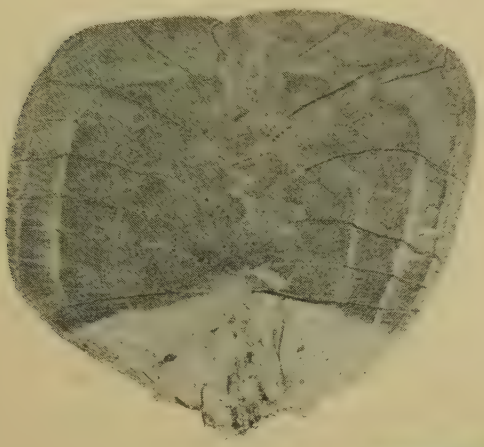


Figure 4. Another scale of same fish as last: showing an additional condition ring on the right side, which was obliterated in the other scale.

Figure 5. Scale from body-area 1 of Cornish pilchard 205 mm. total length, collected 10. Aug. 1950: first three rings of yearly type, next two of intermediate type (see right side).

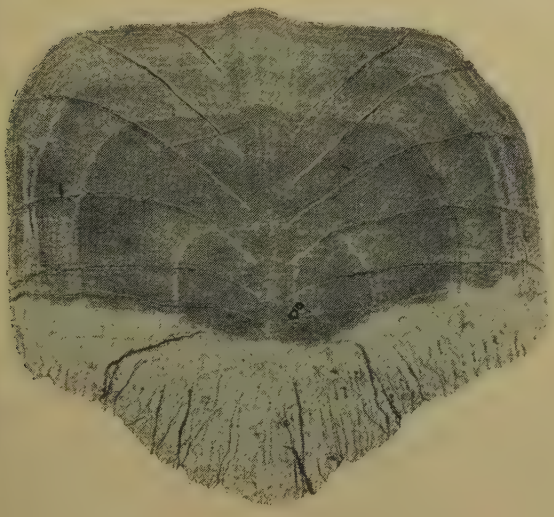


Figure 6. Scale from body-area of same fish as last: first two rings of yearly type, next three of condition type, the two last showing "casquette" in the apical region.

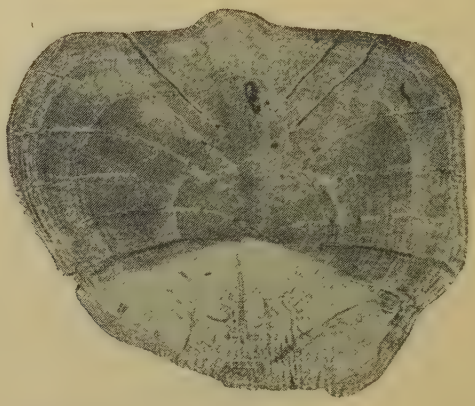


Figure 7. Scale from body-area 4 of same fish as last: as in Figure 6, but one condition ring obliterated on right side.

Figure 8. Scale from body-area 1 of Cornish pilchard 209 mm. total length, collected 10. Aug. 1950: first two rings of yearly type, next two of condition type, both with "casquette".

Figure 9. Scale from body-area 4 of same fish as last: second ring now of intermediate type (see remarks in text) and one condition ring obliterated on right side.

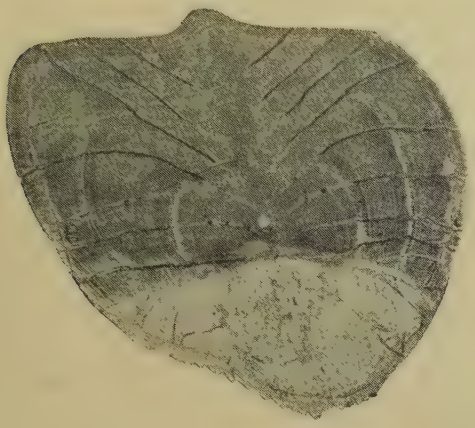


Figure 10. Scale from body-area 6 of same fish as last: as in Figure 9, but one condition ring obliterated on both sides.

Figure 11. Scale from body-area 1 of Cornish pilchard 215 mm. total length, collected 10. Aug. 1950: first two rings of yearly type, next three of condition type (middle one has "casquette"), and a sixth ring only clear at upper corners.

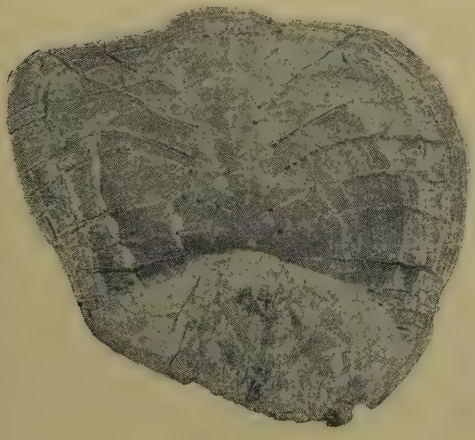


Figure 12. Scale from body-area 4 of same fish as last: second ring now of intermediate type, one condition ring obliterated on both sides.

The problem of age-determination.

The practice of the English workers, who take scales from the anterior part of the body, is thus a good one for their pilchard species. It will also simplify any future study of the fish-length/scale-length relationship, since the scales of the same body-area vary least in size on this part of the European pilchard. Elsewhere on the body there is considerable variation in scale-size on even a small area of one and the same fish in this, though not in other, pilchard species (T h o m p s o n 1926).

Even on these anterior scales there can be marked interference between condition rings, as shown by Figures 3 and 4. It is definitely necessary to read more than one scale from each fish, and to try to recognize the condition rings and count one year for each, whether or not it can be traced all round the scale.

Interpreting the scales with these findings in mind, the writer found his readings did not always agree with those made previously by various workers at the Lowestoft laboratory. For example, there was agreement about the scales in Figures 1 and 2, but disagreement about those in Figures 3 and 4, which are both from the same fish; the writer's determination of the age of this fish was a year higher, for reasons already given. This was the usual kind of disagreement.

The following summary indicates the extent and significance of the agreement and disagreement between the Lowestoft investigators and the writer, who read the same scales. The writer first read all the scales in a sample, checked the results against the Lowestoft records, and made a second reading for the ones that disagreed.

Sample M.1 (75 fish) — Agreed on first reading for 69 (92 %), and on second reading for 1 (1·3 %) more. Of the disagreements, 4 were considered "non-significant", since one or both of the readers entered his reading with a query in each instance; but this did not apply to the 1 remaining disagreement (1·3 % of the whole sample), which was thus considered "significant". The Lowestoft reading for this specimen was lower than the writer's.

Sample M.2 (100) — Agreed on first reading for 89, then for 1 more: disagreements included 8 which were significant in the above-mentioned sense, the Lowestoft readings all being the lower.

Sample M.3 (100) — Agreed on first reading for 74, then for no more: 12 significant disagreements, the Lowestoft readings being the lower for 11, the higher for 1.

Sample M.4 (100) — Agreed on first reading for 70, then for 3 more: 16 significant disagreements, the Lowestoft readings all being the lower.

Sample M.5 (100) — Agreed on first reading for 67, then for 2 more: 18 significant disagreements, the Lowestoft readings all lower.

Sample M.6 (100) — Agreed on first reading for 62, then for 2 more: 26 significant disagreements, the Lowestoft readings all lower.

Sample M.7 (50) — Agreed on first reading for 35 (70 %), then for

3 (6 %) more: 10 (20 %) significant disagreements, the Lowestoft readings all lower.

Sample PV.1 (120) — Agreed on first reading for 86 (71·7 %), then for 9 (7·5 %) more: 13 (10·8 %) significant disagreements, the Lowestoft readings being lower for 12, higher for 1.

Sample PN.1 (100) — Agreed on first reading for 72, then for 8 more: 11 significant disagreements, the Lowestoft readings being lower for 5, higher for 6.

(Sample PW.4 was not read for age by the writer, as the scales were in bad condition; only the edges were examined).

For the total of 845 fish, there was agreement on the first reading for 624 (73·8 %), and on the second reading for 29 (3·4 %) more: and "significant" disagreement about 115 (13·6 %), and "non-significant" disagreement about 77 (9·1 %). The main interest attaches to the percentage of "significant" disagreements. This seems uncomfortably high, especially as there are also about 9 % of fish (the "non-significant" disagreements) about whose age there was real uncertainty on the part of one or both readers. The writer's impression is that at least 5 % of all determinations will always be doubtful, which makes it very important to deal with the 14 % or so of cases which independent workers can interpret confidently but differently. It will be seen, too, that these differences are not random differences, the Lowestoft readings being usually the lower. But it is noteworthy that the above-mentioned scale samples were read by different English workers (the readings for one or two samples being made by the same man, for other samples by another, and so on), so that the present writer agreed better with some of them than with others.

The significance of the "condition rings".

As was mentioned earlier, the investigations on the Australian pilchard showed that the sharp rings on the scales do not necessarily occur in precisely the same years as those in which the fish matures, although in that species, the season of formation is always the spawning season in the years in which the rings do occur. In the Cornish pilchard, however, even the latter often does not apply. The ring of this type on the clupeid scale should not, therefore, now be called a "spawning ring".

The question that remains is whether the formation of this type of ring can still be ascribed to annual change in condition of the fish, as Zamakhaev thought, even though this change may not coincide with the spawning period.

Hickling (1945) showed that the body-fat content of uniform-sized Cornish pilchards is generally highest for the year from November to January, then falling very abruptly to a yearly minimum in March and April. Thereafter the fat content increases gradually and irregularly through the summer and autumn. It was shown above that the ring in question does not appear at the edge of scales collected in September, and only to a very small extent (0·8 per cent. of specimens) in November

material; but it is present in 14·0 per cent. of specimens taken in early February, when the fat content is usually falling very fast.

The 16·7 per cent. of early July specimens with sharp rings at the scale-margins are hard to explain on the basis of Zamakhaev's hypothesis. However, the base of this percentage was only 36, whereas for each of the others it was 80 or more. Possibly the period from March or April to July is too short to allow appreciable new growth at the edge of the scale, especially as spawning is then taking place.

Of the 26 fish whose scales showed these marks at the edge, 2 had been recorded as having a good quantity of intestinal fat, 11 a moderate amount, 5 very little, and 1 as having no fat, there being no such data for the remaining 7. These classifications had been made by eye. There were no data on body-fat content of individual fish. Hickling (1945) showed that seasonal fluctuations in intestinal fat content run generally parallel with those in body-fat content, although he added that "the correlation is a general one only".

Thus the best of the available data on the Cornish pilchard fit Zamakhaev's hypothesis quite well, and the rest, while not agreeing particularly well, are not necessarily inconsistent with it.

The idea that the sharp rings on clupeid scales are caused by fracture of scale margins, due to a sudden loss of girth in the fish, thus remains an attractive one. As the writer pointed out earlier (1949), it was actually first proposed by Johnston (1905) to explain "spawning marks" in Atlantic salmon, although it was abandoned by later workers on that species. No opinion is expressed here about the applicability of the hypothesis to salmon "spawning marks", which in any case are very different from the marks on clupeid scales.

The increasing representation of sharp rings on scales of fish of successive ages cannot, as has been shown, be associated with spawning in the Cornish pilchard; but, both in this form and in the Australian pilchard, it could be associated with the seasonal fluctuation of body-fat content (condition) within the year. There is clear evidence that this fluctuation increases greatly in amplitude in the first few successive years of a pilchard's life, although the increase is not continued in the later years (see Dill 1921, Clark 1928 and 1934, also discussion in Blackburn 1950, for *Sardinops caerulea* and *S. neopilchardus;* and Fage 1920, pp. 71—2, Wagner & Ramalho 1936, especially Fig. B., and Hickling 1945, for *Sardina pilchardus*). This phenomenon is not necessarily connected with sexual maturity, as Hodgson & Richardson (1949) have found extremely high percentages of fat in virgin Cornish pilchards: it is probably related to length or age.

If Zamakhaev's hypothesis is accepted, the increasing amplitude of the fat-content fluctuation could explain the fact that the rings in question are sometimes not sharp at all in the early years of life. Sometimes the ring is scarcely distinguishable from the yearly type at these ages (Victorian fish, see references above), or it may be "intermediate", as shown in this study. An intermediate ring is regarded as a composite of an ordinary yearly ring and an early type of "condition ring", the

latter being much less distinct than is usual at greater ages, and not necessarily present all round the scale. It is not even necessary to regard these early condition rings as being formed by fracture, as the modified Z a m a k h a e v hypothesis admits absorption effects in part (B l a c k b u r n 1950, and below). The idea may be understood from the appearance of the second ring in Figure 9, as seen on the right. The main ring is undoubtedly of the yearly type, obliterated in part by an incomplete and weakly developed condition ring. There seems to be little variation in fat content during the first year of pilchard life (references above), and it is seldom that anything resembling even the early type of condition ring is found associated with the first ring.

There seem, then, to be reasonable grounds for regarding the sharp rings on clupeid scales, and even their "intermediate" precursors at slightly earlier ages, as registering loss of condition in the fish. They are therefore called "condition rings". A different interpretation of these rings may yet be found, but it is convenient to have a term for them which is, for the time being in accord with what is known about them.

The previously published modification of the Z a m a k h a e v hypothesis (B l a c k b u r n 1950) must now be amended to accommodate the case of the Cornish pilchard. It may now be written as follows:—

In some clupeids the annual deterioration of body condition, which may or may not accompany gonad maturation, occasions absorption of the margins of all scales, whereby a concentric ring is formed. More or less simultaneously, the loss of girth causes skin shrinkage and consequent fracture of the dorsal and ventral margins of scales, which is perhaps facilitated by a weakening of the edges during the absorption process. This effect is especially marked in the middle of the trunk, and may or may not occur elsewhere. On young fish, in which the change in condition is less marked, there may be only absorption, and that not necessarily all around the scale. In still younger fish there may be no such effect of any kind. The rings of this type may be called "condition rings"; they often interact with the ordinary (yearly) rings of which one is formed in every year of life, and sometimes with one another.

This hypothesis may, of course, have to be amended again, or even rejected, as further observations are made. It is hoped that this contribution will stimulate further enquiry on the subject.

It was stated above that interaction between condition rings is rare in the Australian pilchard. Plate 7, Figure 1, of the writer's 1949 paper shows an instance of it, in a scale that was formerly held to indicate an age of four years. In the light of the present work it can now be seen that the age is five years, since there is an additional condition ring which can be seen (with casquette) in the upper right-hand corner. Elsewhere on the right-hand side of the scale this ring appears to be fused with the previous one, and for this reason it was not originally counted — exactly the type of mistake that is dealt with in the present paper. A re-examination of the Australian pilchard scales showed this to be an isolated error, and the conclusions of the studies on them are not

significantly affected. The scarcity of such instances in the Australian pilchard material is probably due to the fact that the species is relatively short-lived (greatest recorded age is six years); if it lived as long as the Cornish pilchard there would be many scales with several condition rings crowded together near the margin, and interaction between them would probably be common.

The writer wishes to thank Mr. R. Elms, of the Lowestoft laboratory, who photographed the scales, and Dr. W. C. Hodgson of Lowestoft, and Dr. H. Thompson, Chief of Division of Fisheries, C.S.I.R.O., Australia, who read the manuscript.

Summary.

Cornish pilchard scales may bear sharp rings of the type previously called "spawning rings" in certain Russian and Australian investigations on clupeid scales. These rings are formed annually in the middle and later years of life, in addition to the ordinary ("yearly") clupeid scale rings which are formed annually throughout the whole life of the fish. When both occur in a year's scale-growth, the former type of ring tends to obliterate the latter. The sharp rings also tend to obliterate one another on scales from the middle of the trunk, making these scales unreliable for age-determinations; in addition, since such obliterations can also occur on scales from other portions of the trunk, such scales should be examined critically for this effect.

These rings do not indicate spawnings in the Cornish pilchard, as they may be formed some weeks before spawning begins, and may occur on scales of virgin fish. There is some evidence that they register annual loss of body fat (condition) in all species in which they have been studied, the ring being formed partly by absorption and partly by fracture of the scale margins.

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Note.

The Herring Atlas.

THE first fishery atlas to be prepared by the International Council is now ready for publication. This is the *Herring Atlas*, which is designed to show, in twelve monthly charts, the average distribution of the main herring concentrations of the north-eastern Atlantic area.

The charts cover Iceland and Norway in the north, the Baltic Sea in the east, the English Channel in the south, and Ireland in the west. The quality of the herrings in each concentration, and the ports at which they are landed, are clearly shown.

The twelve charts, printed in red, green, and black, are laced together in a stout canvas cover, 24×18 inches in size, and the explanatory texts and marginal notes are printed in three languages, English, French, and Danish, thus giving the Atlas a truly international character.

It should be of value to all members of the Herring Industry, as well as to schools and colleges; for those members of the Trade who are interested only in certain months of the year, single monthly charts are available.

The price of the Atlas is 30 Danish kr. and single charts will be sold at 3 Danish kr. each, postage not included. Applications for copies should be addressed to:—

Messrs. Andr. Fred. Høst & Son,
Bredgade 35,
Copenhagen, Denmark,

or, in the case of residents in the United Kingdom, to:—

Dr. W. C. Hodgson,
Fisheries Laboratory,
Lowestoft.

(The prices in the U. K. are 30/- and 3/- respectively.)

Reviews.

J. S. Colman. "The Sea and its Mysteries." 285 pp., 36 figs., 16 pl., 1 chart. G. Bell and Sons, London, 1950.

Dans ce livre, qui est un aperçu général sur les sciences de la mer, l'auteur, biologiste, a fait une large part à l'océanographie biologique. 60 pages, soit 1/5 environ, sont consacrées aux propriétés physiques et chimiques de la mer, la forme des océans, la salinité, température, la circulation profonde, les courants, les vagues, et les marées. Les autres chapitres, soit les 4/5 du volume, traitent du plancton, de la vie dans les profondeurs, des récifs de coraux, des animaux et des plantes vivant sur les parties du rivage comprises entre les laisses de haute et de basse mer, les poissons, les baleines et leurs migrations, l'océanographie appliquée à la pêche.

Dans un ouvrage que l'auteur cite avec raison comme le meilleur livre d'océanographie en langue anglaise: *The Oceans* de Sverdrup, Johnson, et Fleming, la proportion est renversée: l'océanographie physique occupe les 2/3 du volume et l'océanographie biologique 1/3 seulement.

L'ouvrage de M. Colman est une mise au point agréable à lire de nos connaissances actuelles, avec une illustration suffisamment abondante pour éclairer le texte. On sent d'ailleurs à plusieurs reprises l'océanographe professionnel, qui a participé à plusieurs croisières océanographiques, et qui ne parle que de ce qu'il a vu. Ce n'est pas le livre d'un amateur qui se hâte de dire tout ce qu'il vient d'apprendre par la lecture rapide d'ouvrages techniques souvent mal compris, et qui aurait écrit aussi bien, si un éditeur le lui avait demandé, un livre sur la médecine ou sur l'astronomie.

Le chapitre le plus original me paraît être celui consacré aux récifs de coraux. M. John S. Colman, qui a fait partie en 1928—1929 de la "Great Barrier Reef Expedition" est alors sur un terrain qu'il connaît bien. "Les récifs de coraux," dit-il, "sont parmi les spectacles les plus merveilleux du monde", et il les décrit avec des détails qui frappent seulement un spécialiste et une sensibilité de poète. Et il donne une explication de ces récifs de coraux en faisant une juste balance entre les théories de Darwin et de Daly.

Le chapitre "Oceanography and Research" est un excellent résumé des expéditions du "Meteor", de "l'Atlantis" et du "Discovery 1". Pour les expéditions plus anciennes, il nous semble — et on nous excusera de le faire remarquer — que justice n'est pas complètement rendue au Prince Albert 1er de Monaco, qui mérite mieux qu'une citation rapide, en passant, surtout

de la part d'un biologiste. Le Prince Albert a, toujours en effet à son actif, deux records qui n'ont jamais encore été battus: il a dirigé personnellement plus de 20 campagnes océanographiques à bord de ses quatres bateaux successifs, "l'Hirondelle I", la "Princesse Alice I", la "Princesse Alice II", "l'Hirondelle II"; il a aussi le record du poisson pêché à la plus grande profondeur, dépassant 6000 m.

M. Colman rend un hommage mérité à l'oeuvre du Conseil International pour l'Exploration de la Mer.

Le chapitre intitulé "The amateur naturalist at sea" est un des meilleurs chapitres du livre. En prenant l'exemple sans doute vécu d'une traversée, à bord d'un cargo, d'Angleterre en Australie par le Cap Bonne Espérance, l'auteur montre l'intérêt que présente à tout instant le spectacle de la mer et de l'atmosphère pour un passager assez instruit des sciences océanographiques.

Le livre se termine par un index alphabétique et par une liste des meilleurs ouvrages d'océanographie de langue anglaise.

L'auteur a parfaitement rempli le but qu'il s'était proposé, non pas d'écrire un traité d'océanographie, mais de décrire quelques aspects des problèmes que pose à la science l'océan et ses mystères, de façon à donner à ses lecteurs le désir de les approfondir davantage, en ne négligeant pas de leur montrer, chaque fois que l'occasion s'en présente, qu'un des charmes de l'océanographie est de travailler dans de beaux paysages.

J. Rouch.

S. Runnström, and others. "Annual report for the year 1948 and short papers". Inst. Freshwater Res. Drottningholm. Rep. No. 29, pp. 1—152. Lund, 1949.

This report is of particular interest. It is the first annual report to be issued by the Institute, and it includes a detailed list of the publications written by the staff and other members of the Fishery Board since the Institute was started in 1932, and also a comprehensive statement by the new director, Sven Runnström, on the subjects being studied at the present time and proposed for future study. The main emphasis of the Institute's programme is to centre on the productivity of the lakes and rivers with a view to increasing the yield of fish. It is also proposed to investigate the introduction of new fish species and new species of animals eaten by fish (including *Mysis relicta*), and to re-examine the rôle of hatcheries.

Twenty short papers (18 in English, 1 in French, and 1 in German) are included, several of which are of very considerable interest to both marine and freshwater biologists, in spite of their necessary brevity. Three papers deal with hydrological problems, and one with a preliminary quantitative study of the planktonic Crustacea of several lakes, while the majority are concerned with various quantitative aspects of the biology of salmonoids, pike, eels, coregonids, and crayfish. Svärdson, in discussing the significance of the various forms of coregonid fish, makes a valuable contribution to the general problem of forms, races, and species of fish, both from the taxonomic and the evolutionary points of view. A study of the fecundity of the char (*Salmo alpinus* L.) by Määr is made from the ecological point of view, but also provides preliminary data on which a study of the relationship between fecundity and the length and weight of the fish could be made.

Svärdson's paper, "Natural selection and egg number of fish" discusses primarily the forces countering the advantages to the species of high fecundity. Of several such forces suggested, Svärdson favours the survival value of

large larvae derived from large eggs as probably the most important force tending to limit the number of eggs produced. If this is so, the relative advantages of large numbers of eggs as opposed to large eggs can be closely balanced, as one has such cases as two extremely closely allied species such as the plaice (*Pleuronectes platessa*) and the dab (*P. limanda*) of about equal successfulness as species, in which the former has a small number of very large eggs while the other has many very small eggs. A striking feature of egg numbers in fish not mentioned by Svärdson is the great variation in number of eggs in the ovaries of fish of the same size. It is not uncommon to find, out of a sample of less than ten fish of the same size and age, the fish with most eggs having two to three times as many eggs as the fish with least eggs. This variation must be the result of environmental conditions, as natural selection would have eliminated the tendency towards small numbers of eggs, the egg size here being irrelevant, as it is a strikingly constant feature within a species. It is to be hoped that this theoretical paper will stimulate investigations by which the hypotheses propounded may be checked.

An interesting experiment on the competition between the fry of trout, char, and trout-char hybrids is described in which 300 of each were reared together in the same trough. At the end of the first season 96 trout, 180 hybrids, and 254 char had survived. Their size distributions are given and discussed.

A short paper by Carl Puke shows that the effect of under-water explosions on fish is very limited.

It is unfortunate that a few of the papers are poorly translated with the result that some ambiguity of meaning is introduced.

A. C. Simpson.

Gordon Gunter. "Studies on Marine Fishes of Texas". Publications of the Institute of Marine Science, University of Texas. Vol. **1**, No. 1., pp. 1—190, 11 figs., tab. 1—75. Austin, Texas, 1945.

Dr. Gunter's paper constitutes the first of a welcome new series of publications recording the results of investigations on various phases of oceanography of the western Gulf of Mexico, at present the least known marine area of the continental United States. The work may well serve as the model of an intensive regional faunistic and ecological survey, and promises well for the standard of future publications of the Institute of Marine Science directed by Professor E. J. Lund.

Texas has a double coastline of barrier islands and mainland shore. The coastal lagoon between connects with the Gulf of Mexico by a few narrow channels through the islands. Landward from the lagoon lie more recently embayed back bays into which the rivers flow. The area where the study was made was Coprano Bay, a back bay, Aransas Bay, part of the lagoon, and the adjacent Gulf of Mexico out to five miles offshore and five miles south on the Gulf beach from Aransas Pass. Under local conditions there results a relatively stable salinity gradient from almost fresh water at upper Coprano Bay to pure sea water in the open Gulf, in a running distance of forty nautical miles.

Against this very suitable background the author presents what is almost a pioneer study of the distributional relationships of 119 species of coastal fishes to salinity, with subsidiary work on temperature relations and life histories.

A large section of the paper and of the copious tables and figures is devoted to the presentation and discussion of data on the separate species,

which in many cases amount to quite substantial individual studies, but the picture of population composition and behaviour as a whole is most interesting. In the analysis of 78,265 specimens, taken in monthly catches with various nets at 31 stations over a period of nearly two years, it was found that 72 species made up less than 1·5 % of the total catch, and only 14 species were taken over a thousand times each, while the croaker *Micropogon undulatus*, the bay anchovy *Anchoa mitchelli diaphana*, and the silverside *Menidia beryllina peninsulae* were taken 36,956 times and thus accounted for nearly half the total catch. It is estimated that *M. undulatus*, *A. m. diaphana*, *Mugil cephalus*, and the menhaden *Brevoortia* sp., have the largest species-masses on the Texas Coast. The commonest families in order are Sciaenidae, Engraulidae, Atherinidae, Cyprinodontidae, Mugilidae, and Clupeidae.

The similarities and differences between fish populations revealed by a comparison with the author's earlier studies in Louisiana are discussed, also the population composition within the ecological sub-divisions of his area.

There is a general migration toward the Gulf in autumn and back to the bays in spring and summer, with a counter movement of a few species that were taken in the bays only in winter. Such seasonal movements are initiated by temperature changes, and the influence of salinity is minor. Mortality during a cold spell in 1942, and the relations of spawning to temperature and salinity in the various species are considered.

The brackish water fauna is marine, with a negligible freshwater element. Many fishes were collected only at the highest salinities, and several living at medium salinities were not taken at the lower salinities. In contrast practically all fishes existing at the very lowest salinities were also taken at the higher salinities. Practically every fish found living at lower salinities, except for four freshwater species, can also live in sea water.

There is a general correspondence between increase of size and increase of salinity, but the situation is not simple and exceptions are cited.

Dr. Gunter has had many years experience in his area, and has not hesitated to invoke the assistance of eminent systematists in cases of difficulty; it would be invidious therefore seriously to question the accuracy of his taxonomic data, even though he admits that practically all his identifications were made in the field. Nevertheless one would have liked to have seen a key to the species included. Just as recent investigations at Plymouth have disclosed cases of two species hiding under one name in supposedly well known British genera, so he finds that in the *Brevoortia* of his area a common genus presents unexpected complications. Numerous instances are known of species which, though difficult to separate on morphological characters, nevertheless have markedly different temperature or salinity tolerances. Taxonomic foundations to ecological and physiological studies can never be too carefully constructed.

Denys W. Tucker.

S. V. Segerstråle. "The Brackish-water Fauna of Finland". Oikos, Vol. **1**, No. 1, pp. 127—141, 7 figs. Helsingfors, 1949.

It is good to see in print the essentials of Professor Segerstråle's paper to the Challenger Society at London in 1949. The huge area of brackish water in the Baltic is very stable and the level may remain unchanged for weeks, so that there is formed a most suitable environment for the study of the effects of salinity gradients on the population. The fauna shows the usual rapid drop in the number of marine species as the salinity falls, and in the

opposite direction, the number of freshwater species also falls rapidly as the salinity increases. Thus the total number of species is high at both ends of the range but very low in the 5—10 ‰ area, even though it is at this range that purely brackish water species are best represented. This paucity of species is, however, not indicative of the number of individuals present, which can be very high indeed, e. g., *Pontoporeia affinis* in one area reached 12,000 per square metre, though figures of 4,000—7,000 for total populations in the mud are more typical. Phytoplankton is also stated to be very rich. An area where *Phragmites communis* and *Fucus vesiculosus* grow together over wide areas cannot fail to interest the ecologist, and Professor Segerstråle points out many of the features and problems of special interest, such as relict glacial forms; the effect of the calcium in the brackish area and its absence in the freshwater lakes on the growth of molluscs common to both; and a caddis larva that uses *Fucus* for its tube — to mention only three. The paper has photographs of the animals sieved out from three areas, reproduced at natural size and density.

Being a reproduction of a short lecture the paper is too small to devote much space to attempts to explain the interesting points raised, and large and obvious fields are quite untouched. Nevertheless the paper is stimulating reading, and a very useful list of papers dealing with brackish water problems is given so that the reader can the more easily look up the answers himself.

J. H. F.

S. G. Segerstråle. "The Amphipods on the coasts of Finland — some facts and problems". Soc. Scien. Fenn., Comm. Biol. **10**, 14, pp. 28, 16 figs. Helsingfors, 1950.

The author surveys some of the more interesting facts revealed by work on Finnish coastal amphipods, and gives a preliminary report of recent observations of the subspecies of *Gammarus zaddachi* and of *G. locusta* in Finland.

In common with many brackish water areas the marine region of Finland is characterized by a small number of species with high population densities. The species found in the region are divisible into three categories — euryhaline forms of marine origin, typical brackish water forms, and euryhaline forms of freshwater origin. A species list of Finnish coastal amphipods and the category to which they belong is given, along with illustrations of typical population densities found in the area. An example is also given of marked annual fluctuations in the population density of *Corophium volutator*.

The Baltic basin harbours a number of glacial relics amongst which are three amphipod species. One of these — *Pontoporeia affinis* — is amongst the most abundant of the amphipod species of the area. Some interesting notes on the ecology and bionomics of this species are given, including details of the breeding cycle and of the formation of the secondary sexual characters in the male. In both of these respects this species shows interesting contrasts to what is known for *Gammarus*. The work on the formation of the sexual characters has led to a revision of the taxonomy of the genus and the suggestion is put forward that the form *P. affinis f. brevicornis* found in Lake Superior is a neotenous form. The secondary sexual characters in the male are shown to be modifications for increased swimming capacity in the nocturnal migrations from the bottom during which pairing occurs. The life of the mature male is short and no feeding occurs during it. Due to the fact that

the female produces only one brood, recognition of year-classes is facilitated, and it can be shown that one to three years are required to attain sexual maturity, depending on the temperature at which development occurs.

Five forms of *Gammarus* occur in the area — the three subspecies of *G. zaddachi, G. locusta,* and *G. dubeni.* The distribution of these in Finnish waters and its relation to salinity are discussed and illustrated. Observations on breeding in the subspecies of *G. zaddachi* were made and an interesting contrast in this respect found between *G. z. oceanicus* on the one hand and *G. z. salinus* and *G. z. zaddachi* on the other. On the basis of this difference and certain morphological divergences it is suggested that *G. z. oceanicus* might be accorded full specific status.

G. dubeni, within its distributional range, in Finnish waters, is found to occupy only very specialized ecological niches. The reason suggested for this is its inability to compete with *G. zaddachi* in environments favourable to that species. *G. dubeni* on the other hand is characterized by great ecological valence in regard to salinity, temperature, and oxygen supply. It is suggested, however, that here we may be dealing with distinct physiological races.

The author is to be congratulated both on an interesting review of previous work in this area and on the value of the new contributions made in this paper. A useful bibliography is appended for those who wish further details of the work quoted.

A. S.

G. L. Clarke and **D. F. Bumpus.** "The Plankton Sampler (an Instrument for Quantitative Plankton Investigations)." Limnolog. Soc. America. Spec. Publ. No. 5, pp. 2—8, 5 figs. Ann Arbor, 1940.

One of the most intractable problems associated with the use of instruments by marine biologists has been that of securing a quantitative sample of plankton by the use of silk nets. Since the end of the last century there has been little advance on the net devised by Victor Hensen for vertical hauls which, by the use of laborious calculations, had been made roughly quantitative. For horizontal hauls with nets at different depths the position was even worse.

A great advance was made, therefore, when a flow-meter was fitted into a plankton net by Dr. Harvey of Plymouth in 1935. In the instrument devised by Dr. Clark and Mr. Bumpus this idea of using a flow-meter has been incorporated into a neat instrument weighing only 10 lb. which can be towed horizontally or obliquely for any desired period.

The instrument may be shortly described as a brass tube five inches in diameter and six inches long, to the end of which a two-foot-long net is attached by a ring and bayonet joint. The tube is mounted in a frame attached to the towing cable and is fitted with planes and pivots which allow it to take up a horizontal position even when it is being towed obliquely. Within the tube is a disk-shaped shutter which can be sent down closed, but which will open when a messenger is sent down the towing cable to strike a trigger device. The shutter may be again closed by sending down another messenger of different shape which operates another trigger system. In the back half of the tube is a propeller geared to a counter and arranged so that it only records water flow when the shutter is open and stops when it closes. The sample is collected in a small glass jar secured to a threaded brass ring or cuff at the tail of the net.

Several samplers may be used on one towing line, as messengers can be released from successive nets as a result of the impact on the uppermost net of the original messenger.

Calibration of the instruments used by the authors showed that the revolutions of the flow-meters varied between 3·8 and 4·5 litres per revolution and they consider the instrument suitable for taking copepods, sagittae, euphausids, and amphipods, as well as for freshwater zooplankton.

Although it has a small opening, Dr. Clarke and Mr. Bumpus consider that it has given adequate samples in American waters. In Europe it seems to have done very useful work in the Norwegian fjords. Here, however, plankton can be very abundant compared with the open waters around the British Isles. In this latter area experiences up to the present suggest that the sampler is too small to give the quantity of plankton required, and there is no doubt that it will be necessary to build a "scaled-up" model for obtaining adequate numbers of fish eggs to carry out a spawning survey.

There has also been some difficulty in the operation of the opening and closing mechanism by the messenger when the towing line is oblique. This is due to the trigger-bars being too short and it is clear that these should be larger in new versions of this instrument. Finally it has been found desirable in some cases to replace the propeller by a more sensitive assembly in order to obtain a more delicate and consistent rating.

These, however, are minor criticisms and there is no doubt that the Clarke-Bumpus sampler has come to stay and perhaps preside over the numerous metered nets now in successful operation.

R. S. W.

Current Bibliography.

Prepared by the Editor with the Assistance of Mr. A. C. Simpson.

NOTE. The scope of the Bibliography is limited in the main to the area covered by the Council's activities, but there are included papers of general interest relating to other areas in North Temperate and Arctic regions and exceptionally elsewhere. Limnological references are not as a rule given, but papers relating to brackish waters and to salmon and freshwater fish studied by the Council are included.

Subscribers and those on the distribution list will receive regularly upon application to the General Secretary copies of the Bibliography printed on one side of the page only, for use in making up card indices.

The Editor will be glad to be advised of emendations and additions to the Bibliography.

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